Performance of 8-year-old provenances cum families of Uapaca kirkina Muell. Arg (Wild loquat) at Nauko, Machinga, Malawi.

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Foreword

Good education should provide solutions to developmental challenges. There is a strong positive correlation between levels of education and economic development in any given country. The major challenges facing humanity currently are associated with the negative effects of climate change, particularly in Sub-Saharan Africa (SSA). Climate change is adversely affecting practically all economic sectors. Africa is projected to have a future associated with scarce water, declining agricultural yields, encroaching desert and damaged coastal infrastructure. The prognosis on the negative effects of climate change for SSA is therefore very grim.

It is gratifying to note that African educators themselves are taking a leading role in assessing what needs to be done for our educational institutions to make significant contribution in providing solutions to the challenges posed by climate change. This Proceedings compilation is an outcome of a symposium organized to share information on climate change challenges for agriculture in SSA; explore methods of mainstreaming climate change knowledge into agricultural education; and identify recommendations on effective policies, institutions and capacity.

The Proceedings lay down the key issues in climate change: who is affected and what direction we are taking if the negative effects presented by climate change are not kept in check. The papers presented present a compelling argument on the role of tertiary education in making meaningful contributions and goes further to present a very reasonable plan of action if we are going to keep on track with climate change adaptation and mitigation strategies.

Educational institutions need to work closely with governments in the whole of SSA in combating the challenges posed by climate change to rural livelihoods.

The symposium was the first of its kind where tertiary agricultural and natural resource management institutions in SSA have taken a leading role in exploring mechanisms by which climate change can be integrated in our institutional curricula. The governments and development institutions should provide the necessary support in working towards addressing the negative effects of climate change.

Acknowledgements

The Proceedings is a compilation of the papers presented by various scientists at the Climate Change Symposium of the African Network for Agriculture, Agroforestry and Natural Resources Education (ANAFE), held in Lilongwe from the 28th of July to the 1st of August, 2008. We are glad that so many scientists found the issue topical and were willing to make stimulating contributions. Over 100 participants from across Sub-Saharan Africa (SSA) and beyond participated in this symposium.

We are grateful that the University of Malawi through Bunda and Chancellor College managed to host the symposium in Lilongwe. We thank the organizing committee headed by Prof. V.W. Saka of Bunda College, University of Malawi for working tirelessly to ensure that the symposium was a success.

We also thank our many sponsors including but not limited to the following: University of Malawi; ANAFE; ICRAF; CTA; FARA; ITOCA and UNDP for generously sponsoring the conference in various ways.

These Proceedings contain information which will remain a useful reference point for workers in the area of climate change.

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Subtheme 1:

Coping With Climate Change And Building The Capacity To Compete Globally

1. Global Warming and the Impacts of Climate Change on Vulnerable Communities and Sectors of Economic Growth

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Abstract

Climate change is real. The emission of greenhouse gases (GHGs), carbon dioxide (CO_2), methane (CH_4), Ozone (O_3), Carbon monoxide (CO), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs) has been increasing from human activity, leading to an increase in warming. The challenge facing mankind is to limit global warming. By far, most of the greenhouse gases are produced in Europe and the United States of America. The sectors that contribute most to greenhouse gases are agriculture, forestry and waste management. Continued increases in GHGs is causing temperature rises, thereby affecting agricultural production in different regions in ways that are difficult to predict. This is already negatively affecting people's livelihoods, particularly in developing countries. Adapting, mitigating and coping with climate change are critical. Government support to the programmes is also of paramount importance.

Key words: Climate change, greenhouse gases, adaptation, mitigation

Introduction

In our efforts to better understand the impacts of climate change on vulnerable communities and sectors of economic growth, we need to formally distinguish between some of the terms that are in common usage, and are often used interchangeably. These are: (i) climate, (ii) climate change, and (iii) climate variability. According to the United Nations Framework Convention on Climate Change (UNFCCC) climate can be viewed as average weather, which represents the state of the climate system over a given time period, and is usually described by the means and variations of variables, such as temperature, rainfall and wind (UNFCCC, 2002), whereas climate variability refers to variations in the mean state of, and other statistics, such as standard deviation, the occurrence of extremes, etc., of the climate on all temporal and spatial scales beyond that of individual weather events (IPCC, 1995). And finally, climate change has been defined as the change in climate that is attributed directly, or indirectly, to human activity that alters the composition of the global atmosphere, and which is in addition to natural variability, observed over comparable time period (IPCC, 1995). Thus, climate variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). However, what should always be remembered is that climate is continuously changing, and that man has for time immemorial adjusted and adapted to these natural changes for survival.

Greenhouse Effect and Global Warming

Greenhouse effect

The earth is surrounded by a blanket of gases, among which are the greenhouse gases (GHGs) carbon dioxide (CO_2), methane (CH_4), ozone (O_3), carbon monoxide (CO), nitrous oxide (N_2O), and chloro-fluorocarbons (CFCs). These GHGs do not impede the transmission of short-wave radiation emitted from the sun, but partly trap and re-emit long-wave (infrared) radiation emitted from the earth's surface. It is the re-emitted radiation that has the effect of keeping the surface of the earth, and the atmosphere, at about 33.0 $^{\circ}$C warmer than it would otherwise be (Houghton, 1991). It is the trapping and re-emitting of heat by these gases in the lower atmosphere that is referred to as the "greenhouse effect". The natural occurrence of these GHGs, keeps the world at a temperature that is essential to life on planet Earth. Hence, the greenhouse effect is a normal component of nature, and not a threat to climate or sustainable livelihoods.

Global warming

However, the threat is from increased emissions of anthropogenic greenhouse gases arising out of man's activity, such as through the burning of fossil fuels and crop residues, which release GHGs into the atmosphere and interfere with the radiation balance. This results in the warming of the earth's surface, a phenomenon that has been referred to as "global warming". Thus, the challenge facing mankind today is to minimize the emissions of these greenhouse gases into the atmosphere so that they should not interfere with the natural climatic system.

Contributions of greenhouse gases to global warming

Over the last 100 years, several greenhouse gases have been emitted into the atmosphere. Carbon dioxide emissions have by far outstripped all the other gases (Table 1.1). A similar trend is also observed for the 1980s, but the contribution of CO_2 is lower, whereas the emissions of methane and chloro-fluorocarbons have increased (Table 1.1).

Table 1.1. Contributions of greenhouse gases to global warming over the last 100 years and during the 1980s

Greenhouse gas	**Percentage contribution of GHGs to global warming**	
	Over the last 100 years	**During the 1980s**
Carbon dioxide (CO_2)	66	48
Methane (CH_4)	15	18
Chloro-fluorocarbons (CFCs)	8	14
Nitrous oxide (N_2O)	3	6
Others	8	13

However, CO_2 is still the major contributor to global warming, and has over the years been enhanced by man's activities, especially fossil fuel combustions, especially in the industrialized nations of western Europe and the United States of America. Over the last 100 years (1900-1999), the emissions of anthropogenic CO_2 from fossil fuel combustion shows that by far most of the emissions are from Europe and the United States (Table 1.2).

Table 1.2. Anthropogenic CO_2 emissions by different countries/continents during the last 100 years

Country/continent	**Greenhouse gas emissions (%)**
United States	30.3
Europe	27.7
Former Soviet Union	12.7
China, India and Developing Asia	12.2
Japan	3.7
South and Central America	3.6
Middle East	2.6
Africa	2.5
Canada	2.3
Australia	1.2

Africa's contribution of 2.5% is very small indeed when compared with the industrialized countries. And in any case, the major contributors to the 2.5% are perhaps South Africa, Egypt and Nigeria; whereas contributions from other sub-Saharan countries at global level are negligible. With increasing human activities, it is projected that greenhouse gas emissions will increase considerably over the coming years. In 1995, out of an estimated 6.46 billion tons of carbon emitted, more that 75% of this was contributed by the developed countries, whereas the developing countries contributed about 25%. However, it is projected that by the year 2035, out of an estimated 11.7 billion tons of carbon that will be emitted, developed countries will contribute 50%, with developing countries contributing the other 50%. This significant shift in GHG emissions has important implications for Africa and the world at large.

The global warming potential of greenhouse gases

The global warming potential (GWP) of the various greenhouse gases is depicted in Table 1.3. Although the emissions of all gases are lower than that for CO_2, especially during the pre-industrial period, their GWPs are quite high.

Table 1.3. Attributes of some greenhouse gases

Attribute	**Greenhouse gases**					
	CO_2	**CH_4**	**N_2O**	**CFC-11**	**FHC-23**	**CF4**
Pre-industrial concentration	290 ppm	700 ppb	270 ppb	Zero ppt	Zero ppt	40 ppt
1998 concentration	365	1745	314	268	14	40
Annual rate of change	1.5	8.4	0.8	-1.4	0.55	1
Global Warming Potential (100 years)	1	23	296	4600	12000	5700
Atmospheric lifetime (years)	5-200	12	114	45	260	50,000

Sectoral contributions of global greenhouse gases

There are many sectors of economic growth that contribute to greenhouse gas emissions. These include the following: energy, agriculture, wildlife, human health, forestry, fisheries, industrial processes and waste management. However, the sectors that contribute most to greenhouse gas emissions are agriculture, forestry and waste management. For example, the contributions by the agriculture sector are as follows: (i) 20% of anthropogenic GHG emissions, (ii) 70% of global N_2O emissions from artificial fertilizers, (iii) 50% of global methane emissions from enteric fermentation and rice paddies, and (iv) 5% of global CO_2 emissions from fossil fuel consumption and biomass burning.

Projected Impacts of Climate Change

Evidence of global climate change

Presently, there is strong scientific evidence that global climate may have already started changing in response to greenhouse gas emissions induced by human activities. Global mean surface temperatures have increased by 0.3-0.6^oC over the last 100 years, and the highest temperatures in this century were recorded during the 1980s and 1990s. In addition, most climate change models predict that global temperatures will rise by about 1.0-3.0 ^0C by the year 2100 in response to a rise in the concentration of CO_2 concentration. This projected change is larger than any other climate change over the last 10,000 years.

The threat of climate change was highlighted during the Earth Summit in Rio de Janeiro, Brazil, in 1992. During the Summit, many countries signed the UNFCCC, which obliges them to periodically update and publish national inventories of anthropogenic emissions of all GHGs that are not controlled by the Montreal Protocol. The aim of the UNFCCC is to stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous human-induced interferences with the climate system.

The changes in climate are likely to have significant impacts on the environment, agriculture, food security, water resources, forests, human health, and sustainable rural livelihoods, especially among resource-poor rural family households. Hence, the need for governments and development partners, including NGOs to address climate change with the urgency that it deserves.

Projected impacts of global climate change

Clearly, any changes in climate in general, and temperatures and rainfall in particular, do have and will continue to have significant impacts on agriculture, food security and sustainable rural livelihoods, the Inter-governmental Panel on Climate Change (IPCC) has projected the following global and local climate change impacts on the agriculture sector and food security (IPCC, 1995): (i) some agricultural regions will be threatened by climate change whereas others may benefit from it. Increased (and/or added) heat stress, shifting rainfall patterns (or monsoons), and drier soils may reduce yields in the tropics and subtropics; whereas longer growing seasons may boost yields in some temperate countries, such as Canada and Russia, (ii) climate and agricultural zones are likely to shift towards the poles. Such shifts could strongly affect agricultural and livestock production so that efforts to shift crops pole ward in response to this could be limited by the inability of soil types in the new climate zones to support intensive agriculture as practiced today in the main producer countries, (iii) soil-water availability will be affected by changing rainfall (or precipitation) patterns. While some regions may become wetter, others are already prone to droughts, and may suffer longer from severe dry spells; (iv) higher temperatures will influence production patterns. Crops may be damaged by higher temperatures, particularly if combined with water shortages, and (v) more carbon dioxide in the atmosphere could boost productivity. In principle, higher levels of carbon dioxide should stimulate photosynthesis in certain plants, especially in the so called C3 plants, as well as pastures and forage grasses; and that this effect could be enhanced or reduced, however, by accompanying changes in temperature, rainfall (or precipitation), insect pests, and the availability of nutrients.

Climate change will also lead to the following socio-economic impacts: (i) loss of property, (ii) increased food risk and loss of life, (iii) damage to coastal protection works and other infrastructure, (iv) loss of renewable and subsistence resources, (v) loss of tourism, recreation and coastal habitats, and (vi) impacts on agriculture, water and fisheries through the decline in soil and water quality

Vulnerability of the Sectors of Economic Growth

Climatic hazards

Over the last two decades, the southern Africa region has experienced a number of adverse impacts of climate change. The most serious climatic hazards have included: (i) intense rainfall, (ii) floods, (iii) seasonal droughts, (iv) multi-year droughts, (v) dry spells, (vi) cold spells, (vii) strong winds, (viii) thunderstorms, (ix) heat waves, (x) landslides, (xi) hailstorms, (xii) mudslides, (xiii) volcanoes, (xiv) earthquakes, and (xv) epidemics. All these climatic hazards impact adversely on all sectors of economic growth, which include: (i) agriculture, (ii) water resources, (iii) forestry, (iv) wildlife, (v) fisheries, (vi) energy, (vii) human health, (viii) industrial processes, and (ix) waste management.

Some of these, especially droughts and floods, increased in frequency, intensity and magnitude in the 1980s and 1990s, and adversely impacted on food security, water security, water quality, energy supply and sustainable rural livelihoods of rural and peri-urban areas communities. It is mostly the resource-poor rural family households, the majority of whom are in sub-Saharan Africa, that are mostly affected by climate change.

Vulnerability of the agriculture sector

Because agriculture is the backbone of the economies of most sub-Saharan countries, it is only fitting that we focus on the vulnerability of the agriculture sector in the southern Africa region. Climate change in the agriculture sector is mainly manifested in the form of floods and droughts, which adversely impact on crop and livestock productivity.

Impacts of droughts and floods on crop and livestock production

During the last two decades, the southern Africa region has experienced significant changes in weather conditions, ranging from the worst and severe droughts in 1991/92 to extreme flooding events, including flush floods, in 2000/01. These droughts, including those that occurred during the 1978/79, 1981/82, 1991/92 and 1993/94 crop seasons, have had irreversible and damaging effects on crop and livestock productivity. The droughts of the 1990s resulted in severe food shortages, malnutrition and hunger, especially among children of smallholder farmers, female-headed households, the elderly, orphans and the urban poor (Sibale *et al.,* 2002). For example, the floods and the associated adverse weather conditions in southern Malawi during the 2001/02 crop season, resulted in: (i) very low crop (maize) production (1.7 mt), (ii) more than 2.2 m people with maize shortage, and therefore requiring food aid assistance, (iii) widespread malnutrition that led to some 10,000 cases of cholera and 161 deaths, (iv) importation of 300,000 t of maize, and (v) serious damage to infrastructure, especially roads, bridges and houses. The droughts also had negative impacts on livestock, especially cattle, goats, pigs and sheep, as pastures were scorched by the blazing sun and increasing soil-water stress. The predicted low and erratic rainfall with high temperatures in the future will result in significant evapo-transpiration rates. Consequently, the severity of moisture stress during the dry season, especially in the drier areas may lead to drought conditions. This impact is exacerbated by the effects of forest clearing in the uplands. Consequently, this results in flooding, siltation of estuary branches and higher riverbed levels, impeding drainage and increasing water logging problems.

Impacts of droughts on food security

It is clear that adverse weather conditions lead to low agricultural production and food insecurity, the status of which would depend on many factors, including: (i) the amount of food reserves stored (emergency stocks), (ii) alternative methods that could be brought to function and produce additional quantities of food, (iii) ability to quickly and swiftly import food from external markets to fill the gaps, and (iv) availability of, and adequacy of the needed infrastructure to transport food aid to the required and affected areas. A good example of serious food insecurity created as a result of a severe drought is during the 2001/02 crop season.

The Vulnerability Assessment Committee Survey Report of July-August 2002 by the World Food Programme indicated that approximately 2.2 m people needed food assistance between September and November 2002 in Malawi, and that this figure would increase to 3.3 million during the lean months of December 2002 to March 2003.

Another example for Malawi is the drought that occurred during the 2002/03 crop season, where government estimated that a total of 655,887 households were affected by hunger due to maize shortages. In the ‘highly’ and ‘severely’ affected areas, households run out of maize by October or November. This situation was also confirmed by a survey conducted in the Mikalango and Mitole Extension Planning Areas (EPAs) in Chikwawa Rural Development Project of the Shire Valley Agricultural Development Division (ADD) in southern Malawi by Saka and Phiri (2005), which showed that 60% of respondent households had no available food reserves between November and March. Thus, droughts, which adversely affect crop production, impact negatively on food security, hence sustainable livelihoods.

Adapting, Mitigating and Coping with Climate Change

Severity and extent of the impacts of climate change

The situation analysis presented above has clearly shown that Malawi, as a nation that is dependent on rain-fed agriculture for its economic growth and development, is highly vulnerable to climate change and/or extreme weather conditions. This means that in the event of severe droughts, as the case has been over the last two decades, there was at times total crop failure, leading to low maize yields, serious food shortages, hunger, food insecurity and malnutrition. On the other hand, floods have resulted in the destruction of crops, disruption of hydroelectric power generation, pollution of water, and increased incidences of diseases, such as malaria, cholera and diarrhea. These have had undesirable consequences on food security, water, health, energy and sustainable rural livelihoods of the most vulnerable family households.

Nonetheless, although the southern Africa region has experienced severe climatic hazards over the last two decades (1980s and 1990s), it has over the last two years (2005-2007) received good rains, a situation that has resulted in increased maize production in a few countries. This has enabled countries such as Malawi and Zambia, countries that have been food insecure for many years, to attain food security at both national and local level. The good harvests have been a result of a combination of many factors, especially: (i) good and evenly distributed rainfall pattern during the growing season, and (ii) the introduction of a "fertilizer and seed subsidy programme" by the two governments that enabled many resource-poor farmers access and purchase subsidized fertilizers at a reduced prices. For example, in Malawi a 50 kg bag of subsidized fertilizer cost MK 950.00 per 50 kg bag during the 2007/08 crop season, whereas commercial price was MK 3,500.00 per 50 kg bag. Presently, the same 50 kg bag is subsidized at MK 800.00; whereas the commercial price is between MK 10,000. and MK 12,000.00. However, despite the attainment of food security at national level, some family households, especially in areas characterized by low and marginal rainfall conditions, are currently faced with the food insecurity problem.

This overview clearly shows that rain-fed agriculture in Malawi is vulnerable to climate change. Hence, there is need for concerted efforts by government, the donor community and other development partners, including NGOs, to put in place measures and strategies for adapting, mitigating and/or coping with the adverse impacts of climate change.

Adapting to climate change

Adaptation to climate change is a process through which people reduce the adverse effects of climate on their health and well-being and take advantage of opportunities that the climatic environment provides. Often, adaptation involves adjustments to enhance the viability of social and economic activities. Adaptation measures to climate change among communities have been considered with two broad areas of activities in mind: (i) measures that reduce vulnerability, and (ii) measures that increase resilience through the utilization of the available common assets.

In addition, adaptation measures are required at two levels: national and local farm level. At national level, there is need to implement policies and strategies that include climate change so as to avert the undesirable effects and impacts of climate change on sectors of economic growth. At local farm level, two broad adaptation options can be distinguished for both the crops and livestock sub-sectors: (i) changes in land use, and (ii) changes in crop and livestock management strategies. The available strategies are numerous, and include: (i) changes in cultivated land area, (ii) changes in crop types, (iii) growing crop species or varieties with higher thermal requirements or those that are tolerant to drought and floods, (v) changes in crop location, including agro-climatic crop specific requirements, (vi) intensive and extensive use of irrigation water, and improved fertilizer use-efficiency to counter the effects of droughts, periodic water stress, and low soil fertility conditions, (vii) control of insect pests and diseases associated with floods and droughts, (viii) improvements in soil management practices to reduce surface runoff and soil erosion, and (ix) establishment and creation of food grain reserves at farm and community levels for safekeeping and storage of harvested produce. The selection of the various adaptation measures and strategies is based on the understanding that these are consistent with current government policies and strategies of poverty alleviation and food security. Further, it is envisaged that the measures and strategies are: (i) compatible with the adaptation measures being implemented in all sectors, (ii) addressing high priority areas, and (iii) affordable and environmentally friendly. It is envisaged that the proposed measures and strategies, whether passive, reactive or anticipatory, will be implemented because they are cost-effective, achievable and will ameliorate the anticipated adverse consequences and impacts associated with climate change.

Mitigating climate change

Since it has been abundantly shown that GHGs resulting from man's activities are responsible for the current unprecedented global warming and the subsequent changes in the climate system, there is need to identify measures for limiting greenhouse gas emissions into the atmosphere. Mitigation measures will need to be developed that aim at reducing GHG emissions through the use of cleaner technologies that do not emit a lot of GHGs, or provide sinks for the emitted GHGs. As such, most of the mitigation measures will be in the energy sector (use of cleaner technologies), forestry sector (planting of trees), and the agriculture sector (improved fertilizer, crop and livestock management).

Specifically, in the forestry sector, strategies will include the planting of various types of tree species in woodlots, forestry plantations, on-farm boundary planting and other agroforestry systems, including various forms of mixed intercropping. There will also be need to: (i) reduce deforestation and the wanton cutting down of trees, (ii) regenerate natural forests, and (ii) protect natural woodlands in protected areas, such as forest reserves and game parks. In the energy sector, strategies will include biomass-based technologies, such as the use of: (i) wood fuel in improved mud stoves and ceramics, (ii) biogas fuel from bio-wastes to produce biogas for cooking and heating, and (iii) briquettes for cooking instead of wood, whereas the non-biomass based strategies would include (i) rural electrification through grid extension, (ii) mini hydropower, (iii) compact fluorescent lamps for lighting, (iv) renewable energy sources (solar cookers, heaters and PVs), and (vi) wind power for water pumping water instead of using diesel and petrol engines. For the agriculture sector, strategies to reduce GHG emissions include: (i) incorporation of crop residues into the soil instead of burning, (ii) good management of livestock manure to reduce methane emissions, and the proper management of nitrogenous fertilizers in rice and upland agricultural soils to reduce nitrous oxide emissions.

Coping with climate change

In trying to cope with climate change, rural family households have tended to employ a number of measures that help overcome the threats in the short-term. Most of these are aimed at ensuring that food is available during the lean months, or at least ensuring that the available food reserves last longer than normal. Generally, these measures also changes people's eating habits, such as reducing the number of meals and quantities of food consumed per day, and the eating of non-traditional staple foods, such as rice, cassava, wild fruits, vegetables and insects. The socio-economic patterns of affected households also undergo many types of changes. For example, household members automatically reduce the purchases of non-food items, exchange or sell off assets and livestock for food or cash, and/or enter into temporary employment arrangements to raise cash for the purchase of food. In extreme situations, households develop an increased dependence and reliance on food aid, handouts and supplementary school feeding programmes.

Response of National Governments to the Adverse Impacts of Climate Change

The threat of climate change was highlighted during the Earth Summit in Rio de Janeiro, Brazil, in 1992. During the Summit, many countries signed the UNFCCC, which obliges each non-Annex 1 Parties to periodically update and publish national inventories of anthropogenic emissions of all GHGs that are not controlled by the Montreal Protocol. The aim of UNFCCC is to stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous human-induced interferences with the climate system. This information is communicated to the COP in the form of "National Communications". For example, Malawi communicated her Initial National Communication (INC) in 2003, and is now preparing the Second National Communication (SNC) for submission to the COP of the UNFCCC by December 2008.

National communications (NCs) focus on the following six broad areas: (i) national circumstances, (ii) national greenhouse gas (GHG) inventory, (iii) vulnerability and adaptation (V and A) assessments, (iv) greenhouse gas mitigation and abatement analyses, (v) other information considered relevant to the achievement of the objectives of the convention, and (vi) constraints and gaps, and related financial, technical and capacity needs. Thus, NCs are designed in such a way that they bring out and highlight measures and strategies for adapting, mitigating and coping with climate change. Further, concerted efforts are made to mainstream climate change into various sectoral polices, strategies and programmes, including agricultural education at all levels of learning. Within the national communication, it is anticipated that measures and strategies will be developed for governments to implement with urgency concerning the mainstreaming climate change into national and sectoral policies, strategies and programmes, and into agricultural education at all levels of learning

Summary and Conclusions

The threats from climate change are real and call for concerted efforts among government and its development partners to develop innovative technological strategies to reduce greenhouse gas emissions, and identify appropriate adaptive and coping measures to address the adverse impacts of climatic change to ensure increased agricultural production, food security at both household and national levels, and reduction of poverty. Efforts are also required to institute measures and strategies that will enable vulnerable communities to cope and adapt to the prevailing climatic risks in a sustainable manner so as to ensure sustainable rural livelihoods.

All sectors of economic growth are adversely affected by climate change, especially the energy, agriculture and water sectors. This calls for concerted efforts in the development of measures and strategies for mitigating, adapting and coping with climate change.

All family households are adversely affected by the impacts of climate change. However, the most affected are resource-poor smallholder farming communities. This is because they do not have sufficient resources (financial) to address issues of climate change. However, family households employ different measures and strategies for coping with climate change, such as "*ganyu*" labour, eating wild fruits and vegetables, or indeed getting off-farm employment in urban centres.

Presently, the response of national governments to addressing climate change issues, has been the preparation of national communications which articulate measures and strategies for adapting and mitigating climate change.

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2. Greenhouse Gas Emission and Nitrogen Availability in Improved Fallow Farming Systems in Nyabeda, Western Kenya

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Abstract

Nitrous oxide, carbon dioxide and methane emissions were measured from different agricultural systems in Nyabeda, Siaya District in western Kenya. These systems were *Tephrosia candida*, *Crotalaria paulina*, natural fallows, and continuously cropped fertilized and unfertilized maize (*Zea mays*). Gaseous emissions are of particular concern due to their role in global warming. Global warming increases the frequencies of extreme disasters e.g. floods, droughts and storms that negatively affect agriculture and increases skin cancer and other health problems. Total N_2O emissions measured over 99 days were higher ($P<0.01$) from *Tephrosia* (584 g N_2O-N ha^{-1}) and *Crotalaria* (554 g N_2O-N ha^{-1}) than from unfertilized maize and natural fallow treatments. *Crotalaria* and fertilized maize emitted 257 and 192 g CH_4-Cha^{-1} respectively and were significantly higher ($P<0.01$) than from other treatments. *Crotalaria* still emitted higher total CO_2 (2967 kg CO_2 –Cha^{-1}) than the other treatments. Fluxes of N_2O, CO_2 and CH_4 followed a similar trend. The findings of this study will be important in developing practices that increase N-use efficiency and reduce greenhouse gas emissions. Despite increased gas emissions from improved fallows, N availability was high following incorporation of their residues. N availability in all the treatments declined over time during the cropping season indicating that the soil N capital is not adequate.

Key Words: *Tephrosia candida*, *Crotalaria paulina*, natural fallows

Introduction

The highlands of Western Kenya are have one of the densest populations in the world 500-1200 people Km^{-2} with farm sizes ranging from 0.2 – 2.5 hectares per household (Hoekstra and Corbett, 1995). Maize is preferred staple food crop, and is often intercropped with beans. Yields are low generally too low to support household needs (i.e. 700 - 2000 kg ha^{-1} and 100 - 500 Kg ha^{-1} for maize and beans, respectively). Other common food crops include bananas, cassava, sweet potatoes, sorghum, groundnuts, cowpeas and kales. In spite of the extreme land pressure, most farmers practice natural fallows on portions of their farms, especially during the short rains (Swinkels *et al.,* 1997), although some farmers are now adopting improved fallow systems using selected agroforestry shrubs for soil fertility improvement (Sanchez *et al.,* 1997; Sanchez 1999).

Unfortunately, recent studies have shown that incorporation of improved fallow residues increase emission of greenhouse gases (Millar *et al.,* 2003), a fact that is of great concern due to their detrimental effect on the atmospheric environment. To date however, there are few reports of trace gas emissions from tree-based tropical agricultural systems (Palm *et al.,* 2002, Millar *et al.,* 2003). Although improved fallows have the potential for carbon sequestration (Nair and Nair (2002), considerable effort is still required to assess the magnitude of this potential under different biophysical and socio-economic conditions.

In this study, we measured emissions of N_2O, CO_2 and CH_4 prior to and following cutting of different fallow species, and subsequent incorporation into the soil. The objective was to compare the amount of greenhouse gas emitted from the different fallows and cropping systems. Knowledge of the contribution of these systems to atmospheric loading of greenhouse gasses will contribute to the development of appropriate organic matter management practices to mitigate emissions and to increase nutrient use efficiency in these systems.

Materials and Methods

Study site

This study was conducted at the KEFRI/ICRAF smallholder experimental farm at Nyabeda in Siaya District in western Kenya. The area lies on coordinates $0^o07'$N, $34^o24'$E at 1330 metres above sea level (Jaettzold and Schmidt, 1982). The area experiences bimodal rainfall patterns with two growing seasons (long rains from March – July; short rains from August – July). Annual rainfall ranges between 1500 to 1900-mm with occasional dry spells during the growing season, and annual mean temperature of 24^0C (Rommelse, 2000). The soils are predominantly P-sorbing alfisols and oxisol originally quite fertile but now very depleted of N and P. Declining soil fertility has therefore been found as the main factor limiting crop production (Hoekstra, 1988). The soils are silty clay loam a pH of 5.4, and total organic carbon of 1.6 % (Nyambati, 2000). Soil organic nitrogen is about 0.12 % while bulk density is 1.13 g cm^{-3}. The soil is classified as fine kaolinitic, isohyperthermic kandiudalfic Eutrodox (Jaettzold and Schmidt, 1982). Extractable P is 1.6 mg kg^{-1} reflecting P deficiency in these soils (Okalebo *et al.,* 2002), which were mitigated through 100kg P/ha application as TSP, along with 100 kg K/ha to cater for any possible K deficiencies.

Experimental treatments

The experiment was established in 1998 as a completely randomized block design with three replicates, and compared improved fallows, natural fallows and continuous maize cultivation. The improved fallow species were *Tephrosia candida* and *Crotalaria paulina* and had previously been seeded directly through intercropping into a growing maize crop in April 2001. Natural fallow treatment species included; *Digitaria abyssinica, Bidens pilosa, Guizotia scabra, Leonotis nepetifolia* and *Commelina benghalensis* which were allowed to regenerate naturally. Comparisons were made with continuous cropping fertilized (100 kg N ha^{-1} yr^{-1} as urea) and unfertilized maize (*Zea mays*). No- tillage practice was tested on *Tephrosia candida* fallow because of its ability to suppress weeds.

The fallows were harvested between 1st and 4th March, 2002. Litter fall collected during fallow growth together with harvested foliage were incorporated into the soil by conventional till to a depth of 15cm on 9th March 2002. Thereafter, uniform broadcasts of inorganic P (Triple Superphosphate, 100 kg P ha^{-1}) and K (Muriate of Potash fertilizer, 100 kg K ha^{-1}) were also applied on all the plots on one week later on 16 March 2002, and planted with maize at a density of 53,333 plants ha^{-1}. Emissions of N_2O, CO_2 and CH_4 were measured prior to, and thereafter periodically following application of fallow biomass between February – June 2002.

Gas sampling and analysis

Sampling was carried out before, and after harvesting mulch from the fallow tree species, land preparation and incorporation of mulch biomass into the soil. Gas sampling was then carried out 3, 6, 10, 13, 17, 24, 38, 60 and 88 days after mulch incorporation into the soil between February and June 2002. Nitrous, methane and carbon dioxide gases emitted from the soil were sampled using gas tight syringes into evacuated 12 ml gas vials from closed flux chambers (0.2 m height by 0.3m diameter) installed into the soil as described by Smith *et al.* (1995). Two chambers per plot (treatment) were inserted to a soil depth of 50 mm, 12 days prior to biomass incorporation. Care was taken during insertion to minimize disruption to the soil especially to soil inside the chambers. The chambers were reinstalled after biomass incorporation after which, they remained *in situ* until the end of the experiment. The chambers were closed for one hour before sampling.

In order to minimize effects of diurnal variation in gas emissions, all gas sampling was done between 10 am – 12.00 noon on each occasion (Baggs *et al.,* 2000). The vials containing sampled gas were kept under refrigeration up to the time they were sent to Wye College in the United Kingdom for analysis using gas chromatography method. The gas samples were analyzed for N_2O, CO_2 and CH_4 in an Agilent 6890 gas chromatograph fitted with an electron capture detector, flame ionization detector and a methaniser. Column and detector temperatures were 50 and 250 ^{o}C, respectively. Gas chromatography using electron capture detector was used for N_2O analysis. The method is highly sensitive for N_2O analysis. Flame ionization detector is highly sensitive and selective for organic gases and was used for the determination of CO_2 and CH_4.

Soil sampling and analysis

Bulk soil samples from six auger holes were taken at depth of 0 – 15cm at the same time of gas sampling for the purpose of determining gravimetric soil water contents. A sub sample of thoroughly was immediately put into a pre-weighed and labeled moisture tins. This was used for determination of soil water content. A second sub sample of about 20 g was then collected from the remaining soil in the bucket and placed in a plastic bag, labeled and sealed with sisal twine. The soils in the bags were analyzed for mineral N and were stored in the refrigerator between collection and extraction (Dorich and Nelson, 1984).

During fallow growth, litter traps were installed in each fallow plot. These were used to quantify litter fall from each fallow treatment. Litter falls from the improved- and natural-fallow treatments were collected every two weeks for determination of chemical composition (or quality) and quantities of biomass incorporated. The fallow species were harvested at the onset of the long rains in March 2002. Harvesting was done between 1st and 4th March 2002. At fallow harvest the aboveground biomass was separated into woody biomass (main trunk and branches), foliage (leaves, small twigs) and pods. The woody material were removed from the plots and fresh weight of other plant components was determined and a sub sample taken to the laboratory for dry matter determination. The samples were oven dried at 40 ^{o}C for 72 hours. Dried sub samples were ground and passed through 20-mesh screen for further determination of chemical composition of residues.

Soil water content was determined gravimetrically. Fresh soil sample was weighed before being dried in an oven at 105 ^{o}C for 48 hours after which it was reweighed (Dorich and Nelson, 1984). Assessment of residue quality was done at Wye College in UK. Sub-samples of litter fall were analyzed for dry-matter yield, total N and total C content using a C/N analyzer coupled to a Europa 20/20 isotope ratio mass spectrometer. Lignin content was measured in an Ankom 220 fiber analyzer. Total extractable polyphenol content were determined using Folin-Ciocalteu reagent in a method adapted from Anderson and Ingram (1993). All data was subjected to ANOVA using Genstat 5 Release 3.2 statistical program ($p<0.05$). Treatment means were separated using least significant differences test (LSD). Correlation of parameters were determined using excel data analysis tool.

Results

Greenhouse gas fluxes and nitrogen availability

The results of this study showed that the daily amount of greenhouse gases released by the various fallows farming systems before pruning was quite low, but increased significantly immediately after incorporation of the mulch residues into the soil (Figure 2.1). However, the pattern of release varied between the various types of greenhouse gases, while the magnitude of release also varied for the different fallow species and cropping systems. For example, the daily rate of N_2O flux increased rapidly during the first few days after incorporation of the mulch residue and reaching a maximum on the tenth day, and thereafter declining steadily for the rest of the growing season in all the treatments (Figure 2.1). In contrast, the daily flux of CH_4 fluctuated during the season with an initial decline in the rate of release during the first six days after mulch incorporation, followed by a slight but steady increase up to the 24th day, and finally declining for the rest of the season. The daily rate of CO_2 release also fluctuated during the season, but with somewhat directly contrasting pattern when compared to daily CH_4 flux. Thus, daily rate of CO_2 release was opposite in magnitude to that of CH_4 whereby the daily CO_2 flux always increased whenever CH_4 flux increased and vice versa (Figure 2.1).

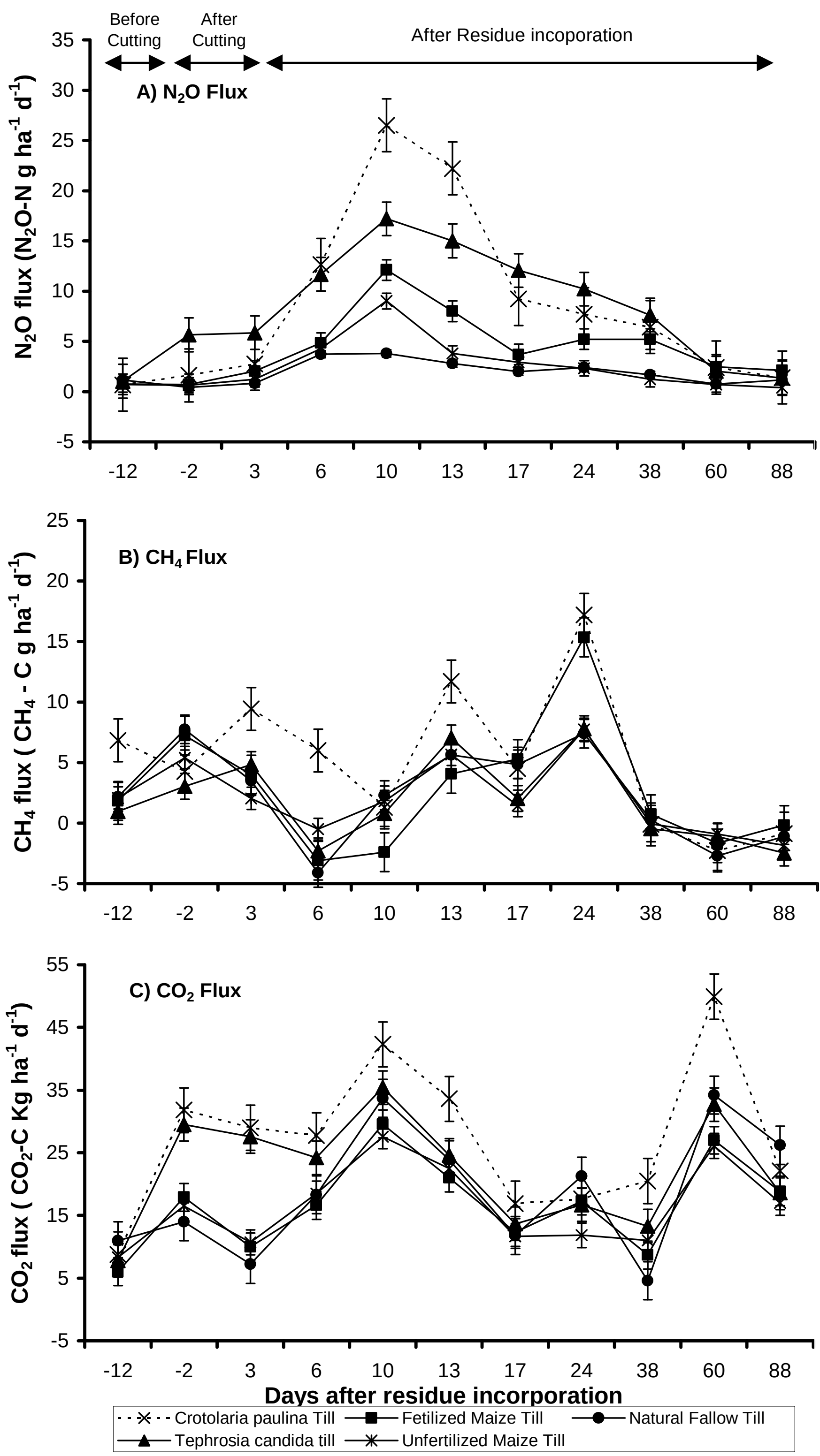

Figure 2.1: Daily gas fluxes measured from different tilled treatments at Nyabeda experimental farm, western Kenya. Error bars represent one ± standard error of the mean

A comparison of the various fallow and cropping systems showed that *Crotalaria* and *Tephrosia* fallows and addition of the respective mulches resulted in significantly ($P<0.01$) higher total emission of greenhouse gases than the other fallow systems, but with *Crotalaria* generally emitting the highest amount of the gases throughout the cropping season (Figure 2.2). Also, fertilizer addition resulted in higher daily greenhouse gas fluxes than unfertilized treatments, which was also higher than natural fallows (Figure 2.2). Expressing the amount of gas flux per unit of mulch residue applied consistently showed that improved fallows released significantly ($p<0.001$) more greenhouse gases that the other farming systems, with *Cotolaria* releasing the highest followed by *Tephrosia* and with natural fallows emitting the least (Figure 2.2).

Mineral soil nitrogen increased after mulch residue incorporation, with higher N availability being associated with improved fallows than natural fallow and maize treatments (Figure 2.3). Available N, however declined over time in all the treatments, and by the end of the season had reached the same levels as at the start of the experiment. Figure 2.3 shows that there was no significant difference ($P>0.05$) in soil mineral N among the treatments before pruning, but increased significantly immediately after biomass incorporation into the soil. Evidently, mineral N from *Tephrosia* fallows was significantly the highest ($p<0.01$), followed by *Crotalaria,* natural fallow, fertilized maize and unfertilized maize being the least ($P<0.01$).

It is interesting to note the contrasting patterns of NO_3^- and NH_4, and their impacts on total mineral N at different times during the growing season. While NO_3^- was low during the early part of the season and high towards the end of the season, NH_4 and total mineral N were initially high but very low towards the end of the growing season. The high NH_4 at the start of the season may be attributed to low mineralization of NH_4 to NO_3 early in the season, but faster mineralization later on. Low mineral N in the soil is usually associated with high NO_3 because of the high leaching losses of this type of mineral nitrogen.

Effects of residue quality

Table 2.1 is a summary of the major quality attributes of the mulch residues from the various fallow cropping systems. Thus, the residues from the two improved fallow systems had almost similar N content, C:N ratios and lignin content. The mulch residues from the improved fallows had almost three times higher N content, significantly lees C:N ratio, almost the same lignin content and more than twice polyphenol content than natural fallows. Polyphenol-N ratios were 0.47, 1 and 0.73 for *Tephrosia*, *Crotalaria* and natural fallows, respectively. The (lignin + polyphenol)-N ratio of *Tephrosia*, *Crotalaria* and natural fallows were 4.81, 4.65 and 14.09 respectively.

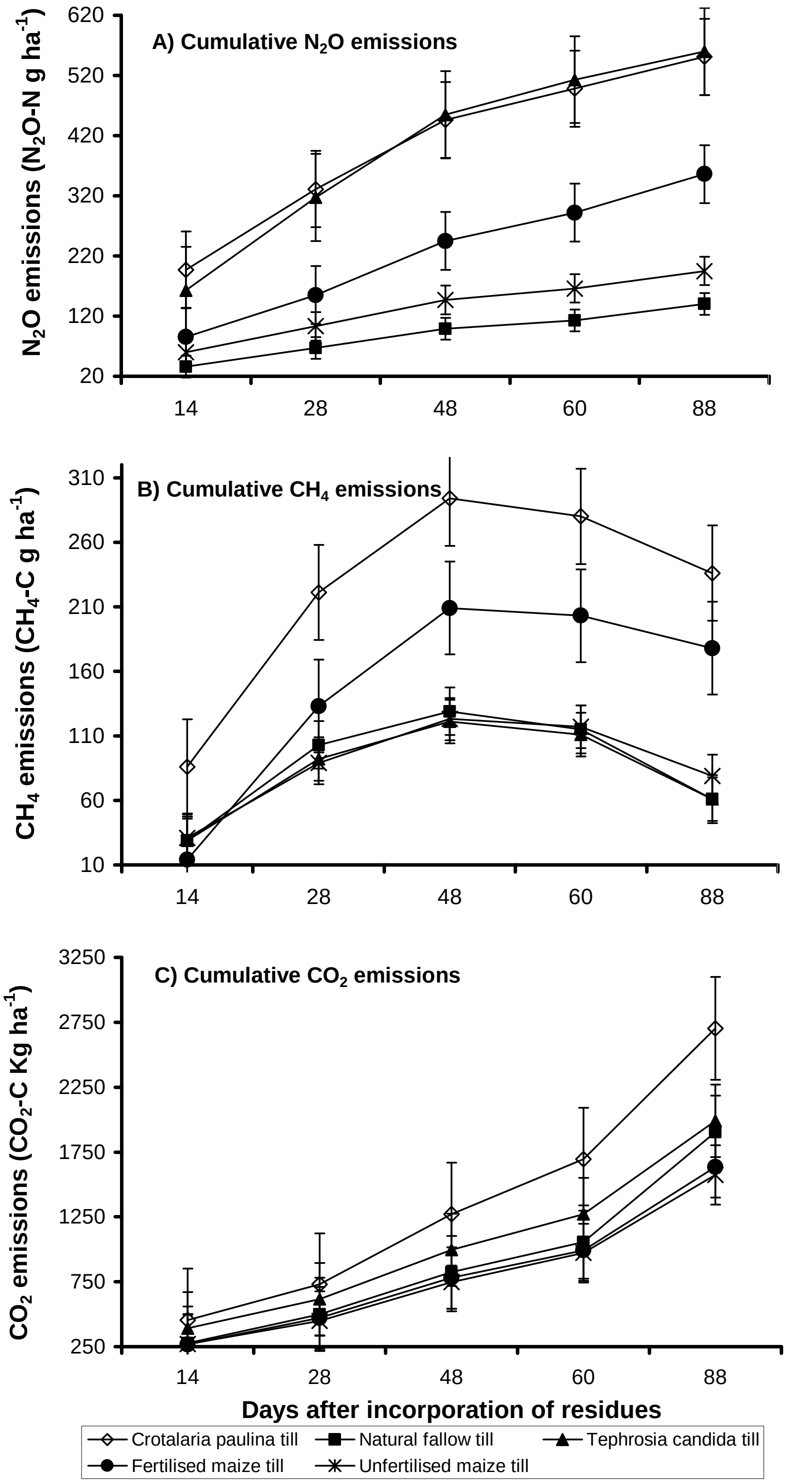

Figure 2.2: Cumulative gas emissions over 14, 28, 48, 60 and 80 days following incorporation of residues. Error bars represent one ± standard error of the mean.

Figure 2.3. Available N measured from different tilled treatments (0-15 cm soil depth). Figures A, B and C represent total N, NO^{-}_{3} and NH_4 respectively. Error bars represent one $\pm$ standard error of mean.

Table 2.1: Chemical composition of applied fallow residues

Treatment	N (%)	C: N	Lignin Content (%)	Total extractable Polyphenol (%)
Tephrosia candida	3.6	11	15.6	1.7
Crotolaria paulina	3.7	11	13.5	3.7
Natural fallow	1.1	36	14.7	0.8

Correlation of these mulch quality properties with gas emission and N mineralization indicates that higher N content of the mulch residue was most important in increasing N_2O emission and N mineralization ($r > 0.95$) than CH_4 and CO_2 emissions ($r < 0.65$). As expected, higher N:C ratio reduced greenhouse gas emissions and N mineralization in all the treatments as shown by the negative correlations between these parameters. Interestingly, higher lignin content of the residues reduced gas emissions from the soil more strongly than N mineralization (Table 2.2). Whereas detergent extractable polyphenol had a strong and positive effect on greenhouse gas emissions ($r > 0.95$), it had a weak though positive effect on nitrogen mineralization ($r < 0.65$). Interestingly, there were no correlations between greenhouse gas emissions with N mineralization.

Table 2.2: Correlations (r) between fallow residue chemical composition and the cumulative greenhouse gas emissions and available soil nitrogen

Greenhouse gas	Chemical parameter			
	N (%)	C:N	Lignin content	Polyphenol Content
N_2O	0.99	-0.99	-0.43	0.94
CO_2	0.61	-0.58	-0.81	0.97
CH_4	0.52	-0.50	-0.90	0.95
NH_4^+	0.98	-0.98	0.44	0.63
NO_3^-	0.95	-0.91	0.49	0.53
Total available N	0.97	-0.99	0.44	0.57

Discussion

Daily greenhouse gas fluxes

Nitrous oxide (N_2O) fluxes increased rapidly soon after residue incorporation probably as a result of increased denitrification caused by rapid stimulation of microbial decomposition (Shen *et al.,* 1989), creation of anaerobic microsites due to placement of residues (Tiedje *et al.,* 1984) and increased carbon supply and substrate for nitrification rates (de Cantanzaro and Beauchamp, 1985). Millar and Baggs (2004) have also reported similar increase in N_2O emissions after residue incorporation. The increase in N_2O emissions after application of N fertilizer may be attributed the fact that fertilization increases N-oxide flux from soil by stimulating microbial processes of nitrification and denitrification, which results in increased gas emissions (Verchot *et al.,* 2004). Goreau and de Mello (1988) showed that N fertilization increased N_2O emissions 15-fold in cowpeas grown in Amazonia. Crill *et al.* (2000) found that fertilizer applications of 122 Kg N/ha to maize in Costa Rica increased N_2O emissions threefold, from 0.5 to 1.8 Kg/ha per season.

This study also showed that N_2O fluxes from improved fallows were positively correlated with NH_4^+, NO_3^- and total N in soils, suggesting that N_2O was produced both during nitrification and denitrification as was found by Millar and Baggs (2004). Li *et al.* (1994) states that both nitrification and denitrification produce N_2O emissions and the practices can enhance or reduce the effects of either or both of these processes. Baggs *et al.* (2001) also found that N_2O emissions were positively correlated with available soil N after incorporation of *Gliricidia* leaves.

CH_4 fluxes fluctuated over the experimental period for all the treatments; declining during the initial two weeks and increasing thereafter, probably because of reducing rates of denitrification. The net soil-atmosphere CH_4 flux is the result of the balance between the two offsetting processes of methanogenesis (microbial production) and methanotrophy (microbial consumption) (Verchot *et al.,* 2004). Net production might have been caused by creation of anaerobic conditions after residue incorporation stimulating methanogenesis (Topp and Pattey, 1997) as was indicated by positive correlation between total CH_4 and CO_2 emissions, as well as greater N availability that is known to inhibit CH_4 oxidation enzymes (Steudler *et al.,* 1989). Use of N fertilizer reduces CH_4 consumption because the enzymes that oxidize CH_4 also oxidize NH_4^+, thus the two compounds compete for enzymes in the soil (Verchot *et al.,* 2004). Net consumption was most likely caused by the formation of aerobic sites produced by second weeding after residue incorporation and declining N availability. Under aerobic conditions CH_4 is oxidized by bacteria through methanotrophy process.

Methane production was highest for *Crotalaria* fallow system, and lowest for *Tephrosia*. Fluxes from fertilized maize treatment were higher than from natural fallow and unfertilized maize treatments. Natural fallow fluxes, however, were lower than those of unfertilized maize treatment despite greater N availability in this treatment that most likely would inhibit CH_4 oxidation. This indicates that there must be other factors, which together with N availability and anaerobic conditions determined CH_4 emissions and these are most likely to be the polyphenol and lignin contents as they were positively correlated with CH_4 emissions among the fallows. Methane fluxes were higher from *Crotalaria* treatment than from natural fallow and *Tephrosia* treatment when quantity of biomass incorporated is taken into account despite having the lowest quantity of biomass applied. This indicates that the quantity of biomass applied did not affect the fluxes. In the study CH_4 fluxes from improved fallows, natural fallows and unfertilized maize treatments were negatively correlated with periodic rainfall. This suggests that CH_4 production was predominantly driven by N availability and residue quality rather than anaerobic conditions.

Initial CO_2 evolution rates from improved fallows following incorporation of residues (between day 3 and 10) were higher. The CO_2 fluxes rapidly increased in the natural fallow treatment between day 3 and 10. Normally at initial stages of decomposition of fresh organic matter, there is rapid increase in the number of heterotrophic organism accompanied by evolution of CO_2. The CO_2 fluxes were relatively high between day 3 and 17 following residue incorporation, which coincided with patterns of N mineralization and denitrification. This indicates that residue decomposition is important in determining CO_2 emissions. The CO_2 flux increased rapidly after day 38 reaching the peak on the 60^{th} day after residue application but again decreased approaching initial rate by 88^{th} day. The increase might have been due to the microsites created during first weeding, which was done on day 34. This could also be attributed to microbial oxidation of atmospheric CH_4 to CO_2 in the soils due to enhanced aerobic conditions during weeding (Duxbury, 1994). *Crotalaria* treatment had higher CO_2 fluxes than all the other treatments. The highest daily flux measured was 49.9 CO_2-$Cha^{-1}d^{-1}$ and was from *Crotalaria treatment*. When quantity of biomass applied is taken into account, the rate of CO_2 evolution in the *Crotalaria* treatment was still higher than both *Tephrosia* and natural fallow treatments. This indicates that the amount of biomass did not play a major role in CO_2 flux.

The results of the study indicate that CO_2 evolution in fertilized and unfertilized soils is strongly influenced by climatic conditions. CO_2 fluxes from the fertilized maize treatments were positively correlated with NO_3^-, NH_4^+ and total N, which indicate NH_4^+ produced was being nitrified to NO_3^-. In the improved fallow treatments, CO_2 fluxes were positively correlated with only NH_4^+, demonstrating the importance of residue decomposition or mineralization in determining CO_2 emissions. CO_2 is formed during the first step of mineralization called aminization, during which amino acids and amines are also formed. The observation that CO_2 and N_2O emissions were strongly correlated indicates that N_2O emissions may have been predominantly produced during the first step of nitrification in the improved fallow systems. The positive correlation between CO_2 fluxes and NO_3^- in the natural fallow further confirms that nitrification potential is strongly correlated with N_2O fluxes from natural and unfertilized systems (Davidson *et al.,* 2000), although in this study there was no significant relationship between NO_3^- and CO_2 fluxes in the unfertilized maize treatment.

Total gas emissions

The emissions from fallows were mainly affected by residue quality and the amount of N fertilizer applied. The amount of N applied from incorporated residues was 266, 185 and 118 Kg N ha^{-1} for *Tephrosia*, *Crotalaria* and natural fallows, respectively. In a similar study in improved fallows in western Kenya, Millar (2002) found that total N_2O emissions over 84 days following incorporation of *Sesbania sesban* residues (2 Kg N_2O-N ha^{-1}) were greater than following incorporation of natural fallows. Millar and Baggs (2004) found that the addition of agroforestry residues to soil increased N_2O emissions. The magnitude of emission was influenced by residue chemical composition or quality. Baggs *et al.* (2001) also measured higher N_2O emissions after incorporation of high quality residues. When quantity of biomass applied is taken into account *Crotalaria* treatment emitted higher N_2O than *Tephrosia* and natural fallow. This might have resulted from high quantity of biomass applied for *Crotalaria* than *Tephrosia* treatment. Maize treatments emitted more N_2O than natural fallow because of generally higher available NO_3^- in the maize treatments.

Crotalaria treatment emitted higher total CH_4 than *Tephrosia* fallow, natural fallow and maize treatments. When quantity of biomass incorporated is taken into account *Crotalaria paulina* still gave higher emissions than *Tephrosia* and natural fallow treatments. Higher emissions from *Crotalaria* residues were related to the lignin and polyphenol contents of the applied residues. Most CH_4 emissions occurred on the first 48 days after incorporation. This was most likely caused by suppressed oxidation of CH_4 in the soils due to increased N inputs especially on the improved fallow treatments. CH_4 oxidation in soils is suppressed in systems that receive high inputs of nitrogen (Steudler *et al.,* 1989). The use of N fertilizer reduces CH_4 uptake because enzymes that oxidize CH_4 and NH_4^+ is the same and thus the two compounds compete for enzymes in the soil. Therefore, in fertilized systems, increased availability of NH_4^+ reduces CH_4 oxidation (Verchot *et al.,* 2004). There is no study that systematically isolates the effect of N fertilization in tropical systems, but work in temperate systems suggests that this mechanism is sufficiently robust to give the expectation that this is the mechanism in tropical systems (Verchot *et al.,* 2004). Castro *et al.* (1994) found that fertilization of pine plantations in Florida decreased CH_4 uptake by a factor of between 5 to 20. Steudler *et al.* (1989), found that N fertilization decreased CH_4 uptake by 33 % in a temperate forest while Mosier *et al.* (1991) found that fertilization of grassland decreased CH_4 uptake by 65 %. Other studies have reported no fertilizer effect on CH_4 uptake rates by soils so questions about this mechanism still remain (Verchot *et al.,* 2004). In this study net total emission of CH_4, measured from all treatments, over 99 days were positive, indicating greater production than consumption of CH_4 in these systems. There was, however, net consumption between day 60 and 88 after residue incorporation, which was attributed likely to declining N availability.

Crotalaria emitted higher CO_2 levels than *Tephrosia* treatment, the amounts which were also higher when applied biomass is considered. Natural fallow emitted higher CO_2 than the maize treatments, which had almost, equal emissions. Higher CO_2 from *Crotalaria* residues was mainly related to the lignin and polyphenol contents. Most CO_2 emissions occurred in the first 28 days and between day 60 and 88 after residue incorporation. Carbon dioxide emissions over the first 28 days were most probably produced during decomposition and between 60^{th} and 88^{th} day produced from oxidation of CH_4. Millar and Baggs (2004) found that there was increased CO_2 emission after residue addition, for example, total CO_2 emitted over 29 days from *Sesbania* treatment was lost in the first 7 days after addition of residues. Aulakh *et al.* (1991) also found that CO_2 emissions from incorporated residues treatments were relatively high during the initial period of incubation.

N availability in the soils

The higher N levels from the improved fallows were attributed to the high quality residue incorporated as compared to natural fallow residues. Differences in the quality of the residues, particularly residue N contents, determine the release of N after incorporation (Palm *et al.,* 2000). The difference in the N levels was also most likely due to the greater amount of N applied as residue in the improved-fallow systems (266 and 185 kg N ha^{-1} in *Tephrosia* and *Crotalaria* treatments, respectively) than in the fertilized maize (100 kg N ha^{-1}) and natural-fallow systems (118 kg N ha^{-1}). Mineralization mainly occurred over a period of two weeks between day 3 and 17 in the improved fallow treatments. Denitrification occurred also over the same period indicating that N release and denitrification are strongly correlated. Mineralization in the natural fallow and the maize treatment occurred between 17^{th} and 38^{th} day after residue incorporation. The study therefore shows N release from the improved fallows is faster than from natural fallow, fertilized and unfertilized maize treatments.

Natural fallow had the lowest available soil NO_3^- in the first 17 days. Available soil NH_4^+ in the natural fallow treatment was, however, generally higher than that of unfertilized and fertilized maize treatments. This indicates that nitrification rates were low in the natural fallow treatment. Available NH_4^+ from the improved fallows was higher than NO_3^- in the first 10 days. This indicates that net mineralization was greater than net nitrification during this period when the rainy season had just started or perhaps the oxidation of NO_2^- to NO_3- was minimal perhaps due to less autotrophic bacteria. Robinson (1957) mentions that NH_4-N tends to accumulate during the dry season as nitrification ceases at water potential just below permanent wilting point whereas mineralization proceeds under slightly drier conditions. Nitrous oxide fluxes from the improved fallows also increased rapidly between day 3 and 10. This indicates that N_2O emissions during this period mainly occurred through nitrification process. Available NH_4^+ in the soils peaked on day 6 for the improved fallows, which probably corresponds with maximum rate of mineralization. Thereafter, available NH_4^+ started declining while NO_3^- increased, almost reaching equilibrium on day 10. Nitrous oxide fluxes were also the highest on day 10. This is most likely because both nitrification and denitrification were contributing to N_2O emissions due to the supply of both nitrate and ammonium substrates. There was rapid increase in NO_3^- levels in the soils between day 6 and 17, which also reflects rapid increase in nitrification rates.

Available NO_3^- and NH_4^+ in soils decreased rapidly in the improved fallow treatments between 17th and 24th day after residue incorporation. This is in agreement with Nandesena (2002), who states that most tropical soils N supplying capacity or N mineralization is relatively low and declines rapidly during cropping season unless N sources are incorporated frequently. While available N was declining in the improved fallow treatment by the 24th day after biomass addition, available N was increasing in the natural fallow and unfertilized maize treatments. This indicates that N released from both natural fallow and unfertilized maize treatment was most likely not going to benefit crop growth.

Most crops require the largest quantity of their N early in the growing season when significant amount of soil organic N is mineralized. Rates of soil N mineralization and nitrification are indicators of the ability of soils to supply N for plant growth and N retention. The microbial mineralization of NH_4^+-N from organic matter is the principle source of plant available N. The rate of production of NO_3^- from NH_4^+ in the process of nitrification influences N losses through leaching and conversion of N gases (Bormann and Likens, 1979). To reduce these losses as stated by Baggs *et al.* (2000), it is necessary to synchronize nutrient release and crop demand, e.g. by delaying incorporation of crop residues until immediately prior to sowing of the following crops. This depends on the quality of the residue applied. Uptake by the following crop would reduce the substrate available for nitrification and denitrification and thus retain N within the plant-soil system. In this study there seems to have been little synchrony between N release and crop N uptake since maize and bean crops were planted on days 7-9 after residue incorporation. The results of the study therefore show that if *Crotalaria paulina* and *Tephrosia candida* residues are to be incorporated, sowing of the crops should be done immediately after incorporation to enhance the synchrony between N release and uptake by plants.

Generally there was greater N release from the improved fallows than natural fallows, the difference being caused by the difference in the quality of their residues which were incorporated as fertilizer. Natural fallow treatment had lower N availability than both fertilized and unfertilized maize treatments despite higher N being applied as residues in the natural fallow treatment. N availability in the fertilized maize treatment was higher than that of unfertilized maize treatment. Unfertilized maize treatment represented the previous fertilizer and cropping regimes and hence it is necessary to replenish the reserves of nutrients, which are removed or lost from soil, for farming systems to remain productive. The study further demonstrates that improved fallows provide a better option for managing N biologically, provided the farmers are willing to make land available for crop fallow rotations.

Effect of quality of residues on total gaseous emissions

Greater N_2O emissions were measured after incorporation of improved fallow residues than natural fallow residue. This was attributed to higher N content and lower C: N ratio of the improved fallows residues that promoted mineralization and subsequent availability of substrate for nitrification and denitrification (Baggs *et al.,* 2000). This could have also been due to higher amount of N applied in the improved fallow treatments than natural fallow. The amount of N applied, as residue was 266, 185 and 118 Kg N ha^{-1} for *Tephrosia*, *Crotalaria* and natural fallows respectively. In improved fallow system in Western Kenya, total N_2O emissions over 84 days following incorporation of *Sesbania sesban* residues were also found to be higher than following incorporation of natural fallow vegetation (Millar, 2002). Increased N_2O emissions were measured from improved fallows than from both fertilized and unfertilized maize treatments. The difference is most likely to have been caused by the higher amount of N applied as residue to the improved fallow systems than fertilized maize (100 Kg N ha^{-1}). Wild (1972) mentions that leaching of mineralized NO_3-N is not as rapid as that of NO_3-N applied as fertilizer due to the time taken for the NO_3-N to diffuse to the large pores and channels through which water drains preferentially. This might have increased NO_3-N available for nitrification in the improved fallow treatments as compared to fertilized maize treatment. Unfertilized maize treatment represented fertilization and cropping history of the previous years if any. Millar and Baggs (2004) also measured higher N_2O emissions after application of agroforestry residues than from un-ammended soil (unfertilized treatment).

Assuming that N_2O emissions were completely derived from residue or fertilizer input, the contribution from fertilizer, corrected for emission from unfertilized maize treatment (Baggs *et al.,* 2000) were lower than Bouwman's, (1996) estimate of 1.25±1.0 %. Crill *et al.* (2000) found that fertilizer applications of 122 Kg N ha^{-1} to maize in Costa Rica increased N_2O emissions three-fold, from 0.5 to 1.8 Kg ha^{-1} and that 1.4 % of fertilizer N applied was lost as N_2O. Weitz *et al.* (2001) in a similar study in Costa Rica, found that N_2O-N losses amounted to between 0.2 and 2.3 % of N fertilizer applications in a maize system.

Total N_2O was positively correlated with fallow residue N content, and is in agreement with Millar *et al.* (2003), and negatively correlated with C: N ratio. This indicates that these parameters are important in determining total N_2O gas emissions after incorporation of fallow residues. Therefore N_2O missions were higher from improved fallows residues than from natural fallow residues. The C:N ratio or the N content has been noted to be important in determining the rate of mineralization. The critical N content required for immediate net mineralization of N to occur is 1.73 % and the critical C:N ratio is 20 (Frankenberger and Abdelmagid, 1985). When organic material with C: N ratio which is greater than 30 is added to the soil, soil N is immobilized during the initial stages of decomposition but when the C:N ratio is less than 20, there is a release of mineral N early in the decomposition process. When the C:N ratio is between 20 and 30 there may either be immobilization or release of mineral N in the soils (Tisdale and Nelson, 1975). In this study natural fallow residue had C:N ratio of 36 therefore immobilizing N which meant ammonia released during decomposition of the residue was being used by the decomposers (Tisdale and Nelson, 1975). Nitrous oxide gas emitted from incorporated natural fallow residues was therefore reduced since mineralization N could not proceed faster. The N contents of the improved fallow residues were greater than 1.73 % while C:N ratios were below 20 and thus there was immediate N mineralization, which then increased their N_2O emissions. Baggs and Millar (2004), however, found that total N_2O emissions measured over 29 days from different fallow treatments were positively correlated with residue C: N ratio and negatively correlated with residue lignin and polyphenol contents.

In this study there was a positive correlation between polyphenol content and total N_2O emissions. Normally higher polyphenol contents in residues can decrease or delay mineral N release from residue reducing the availability of N for nitrification and denitrification and hence low emissions. Polyphenols may bind to plant protein forming relatively insoluble recalcitrant N compounds reducing their availability for microbial attack and may also bind to soil enzymes lowering or inhibiting their activity (Baggs *et al.,* 2001). Polyphenol contents of *Crotalaria* and *Tephrosia* residues were 3.7 and 1.7 % respectively but had almost equal total N_2O emissions. Natural fallow residues with lowest polyphenol content of 0.8 % would have emitted higher total N_2O emissions but this was not the case. This indicates that polyphenol content of the improved fallows did not affect N_2O gaseous emissions. In this experiment rainfall may have leached soluble polyphenols down the profile (Handayanto *et al.,* 1994), thereby reducing the influence on N_2O emissions. Baggs *et al.* (2001), however, found N_2O production in a controlled environment experiment to be influenced by polyphenol content and protein binding capacity from agroforestry prunings. Emissions from high quality *Gliricidia sepium* prunings were significantly higher ($P<0.05$) than from *Calliandra calothyrsus* and *Peltophorum dasyrrachis* prunings, despite similar C: N ratios. This was attributed to the higher polyphenol contents and protein binding capacities of the *Calliandra* and *Peltophorum* (Baggs *et al.*, 2001).

Residue lignin content did not have any significant relationship with total N_2O emissions. The lignin contents of *Crotalaria* and natural fallows were lower than the threshold value of 15 % above which mineral N release is usually reduced (Palm and Rowland*,* 1997) while that of *Tephrosia* fallow was above, but still emitted higher N_2O than *Crotalaria* and natural fallow. This study shows that total N_2O emissions were predominantly determined by residue N content as was demonstrated by (Gathumbi *et al.,* 2002) and C:N ratio. Total CO_2 emissions were also positively correlated with residue N content. This was possibly due to microbial decomposition after residue incorporation (Shen *et al.,* 1989) as indicated by positive correlation between total N_2O and CO_2 emissions over the first 48 days after incorporation. Like N_2O emissions, CO_2 emissions were negatively correlated with C: N ratio. This indicates that N content and C:N ratio could be used as parameters for determining CO_2 emissions after residue incorporation. Carbon dioxide emissions were negatively correlated with lignin content and positively correlated to polyphenol contents. Millar and Baggs (2004), however, found that total CO_2 emissions over 28 days were positively correlated with residue C:N ratio ($r = 0.88$) and negatively correlated with residue polyphenol content (r = -0.95). Higher CO_2 from the *Crotalaria* treatment is most probably related to its low lignin content.

Both N content and C:N ratio did not affect CH_4 emissions. Greater CH_4 emissions measured from *Crotalaria* than *Tephrosia* treatment is most likely due to the difference in their residues' lignin content. *Crotalaria* residue had lower lignin content than *Tephrosia* treatment and is most likely to have caused increased CH_4 emissions. Carbon dioxide and CH_4 emissions had similar relationship with lignin and polyphenol contents. This indicates these two parameters can be important for determining total CO_2 and CH_4 emissions after incorporation of fallow residues.

Effect of quality of residues on N availability

The patterns of N release observed in the present experiment were influenced by the quality of prunings and the amount of N added to the soil. N released from improved fallows followed the same pattern and was higher than from natural fallow. This is in agreement with Palm *et al.* (2000), who found that the different quality of residues, determines N release after incorporation. Available N was positively correlated with N content of residues except on day 24 and 88 after residue application when the correlation was negative. The negative correlation must have resulted from declining N levels in the improved fallow treatments which had higher residue N contents and increasing N levels in the natural fallow treatment which had low residue N content as from day 24 after biomass addition. This determined the correlation between available N and C: N ratio, which was negative except on days 24 and 88 after residue incorporation when it was positive.

The initial N content and C: N ratios have been considered to be the most important plant factors governing decomposition and N release from plant material. The critical N content required for immediate net mineralization of N to occur is 1.73 % and critical C: ratio is 20 (Frankenberger and Abdelmagid, 1985). The N contents of the improved fallows were all above 1.73 % and both had C: N ratio below 20. The results of this study therefore agreed with the expected trend where N release from improved fallow treatments was greater and faster than in the natural fallow treatment. Incorporation of low quality material can often result to temporary immobilization of soil N and may have occurred after incorporation of natural fallow residues. Total available N released from the *Tephrosia candida* residues was, however, greater than from *Crotalaria paulina* residues although the residues had similar C: N ratios and more or less equal N contents. This could be attributed to the greater polyphenol content of the *Crotalaria* residues. Polyphenol contents may have played a role in regulating N release among improved fallows treatments whereby *Tephrosia* with less polyphenol content, had greater N release in the first 17 days after residue incorporation. The polyphenols of *Crotalaria paulina* may have bound the plant N, thereby reducing slightly the N release from residues. Handayanto *et al.* (1994) found that where leaching occurred, polyphenol effect on N release was reduced due to removal of polyphenols that bind proteins. Both total N and NH_4^+ were positively correlated with residue polyphenol content on days 38 and 60 after residue incorporation. This could have been caused by reduced effect of polyphenols due to leaching arising from high periodic rainfall.

Palm and Sanchez (1991), found the ratio of polyphenol: N as the parameter, which could best be used to predict N mineralization of various tropical legumes with critical values of 0.5. Polyphenol: N ratio mainly played a role among the improved fallow treatments. Fox *et al.* (1990), however, found that N mineralization from legume residues correlated more strongly with (lignin + polyphenol): N ratio. Kachaka *et al.* (1993) concluded also that lignin: N ratio or with (lignin + polyphenol): N ratio is the parameter which best correlated with N mineralization from legume prunings. Materials with (lignin + polyphenol): N ratio of less than 10 is generally found to result in fast N release (Mafongoya *et al.,* 1998). This is in agreement with what was observed in this study. In this study (lignin + polyphenol): N ratio better correlated with N mineralization than polyphenol: N ratio.

Lignin content alone did not play a major role in the N release from the studied residue types. Lignin content is however also capable of reducing availability of both carbohydrates and protein by complexing them, just like polyphenols (Swain, 1979). Fifteen percent is the threshold value of lignin contents above which mineral N release is usually strongly reduced (Palm and Rowland, 1997). The lignin contents of *Crotalaria* and natural fallows were lower than this threshold value. *Tephrosia* residues, despite having lignin content of 15.6 %, still had higher N release than both *Crotalaria* and natural fallows. The effects of lignin content on *Tephrosia* fallow must have been masked by its lower polyphenol content as compared to *Crotalaria* and natural fallows. The findings of this study further confirm that C:N ratio alone is insufficient to predict N release. Low N availability in the natural fallow system achieved in traditional cropping systems without long fallow periods, is below the threshold of acceptable level of soil productive functions Gulbert (2002).

Conclusions

Adoption of the improved fallows instead of natural fallow, unfertilized or fertilized maize systems may increase N_2O, CO_2 and CH_4 emissions. This is based on the cumulative emissions of these gasses measured over 99 days of sampling. Both *Crotalaria paulina* and *Tephrosia candida* emitted higher N_2O and CO_2 than natural fallow and maize treatments. *Crotalaria paulina* emitted higher CH_4 than natural fallow, maize treatments and *Tephrosia candida* fallow.

The study shows that despite increased gas emissions from improved fallows, soil N availability was high following incorporation of improved fallow residues than from natural fallow residues and fertilizer application. Increased soil N availability in the improved fallows was related to the quality of residue applied. Nitrogen availability in all the treatments declined over time during the cropping season indicating that the soil N capital is not adequate and thus there is need for frequent application of organic residues to increase organic C and N necessary for maintaining N capital.

The results indicate that there is potential of N_2O losses to be reduced and N to be retained within the system by improving synchrony of N supply with crop demand through timing of both incorporation of residue and planting of crops. Residue quality plays an important role in determining gas emissions and N release after residue incorporation. This study shows that residue N and C: N influenced N_2O and CO_2 production.

Greater N_2O and CO_2 emissions were measured from tilled than from non-tilled treatment, however, higher CH_4 magnitudes were measured from no till than from tilled treatment. Tillage practice therefore has the potential to contribute to greenhouse effect as compared to no-tillage. Tillage and non-tillage practices did not affect significantly N availability hence non-tillage of improved fallow residues could be adopted without negatively affecting N availability for crops whilst reducing gas emissions. The results of the study also indicate that *Tephrosia candida* is a more promising fallow species than *Crotalaria paulina*. Greater total CO_2 and CH_4 emissions were measured from *Crotalaria paulina* than *Tephrosia paulina* treatment. Nitrogen release from *Tephrosia* residues was higher than that of *Crotalaria*, which resulted in faster growth of the crops in the *Tephrosia* plots.

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3. Adaptation Strategies And Actions To Climate Change Impacts—A Case Of Mulanje Mountain Forest Reserve And Its Surroundings - Malawi

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Abstract

Although a relatively new and little understood phenomenon in Malawi, the impacts of climate change are slowly becoming a common occurrence, often times with catastrophic consequences. A rapid response assessment was carried out around the Mount Mulanje Forest Reserve to assess knowledge, attitude and practices (kap) by the local population in respect of climate change related responses. In addition, a desk-top assessment of climate related data was made to relate people's perceptions and claims about climate change related occurrences and issues. This paper provides a case for the better understanding of climate change in Malawi and how communities adjust to climate change scenarios. The paper outlines a number of coping strategies communities engage themselves in and relates these efforts to issues of environmental conservation and management currently under way through a multi-stakeholder approach.

Key words: Adaptation, climate change, livelihoods, resilience, Mulanje Mountain Forest Reserve

Introduction

Like in many other developing countries, the severe impacts of climate change have been noticeable in Malawi, particularly in the past two decades. The most serious climate related catastrophes have been dry spells, seasonal droughts, intense rainfall, floods and flush floods (Action Aid, 2006). Some of these especially droughts and floods, have since increased in frequency, intensity and magnitude over the same two decades, and have adversely impacted on food and water security, water quality, energy and sustainable livelihoods of the most rural communities.

This case study focuses on communities living within the five – seven kilometre band surrounding the Mulanje Mountain Forest Reserve (MMFR) located between latitudes 15°50' - 16°03' South and longitudes 35°30' – 35°47' East in Malawi. The site was selected from the perspective of the communities' interaction with the reserve and their livelihoods that have a direct bearing on climate, climate change and mitigation issues. The study therefore specifically looks at how communities, reliant as they are on the natural environment especially the forests, impact on the climate change issues (and how they are impacted by the same climate change scenarios and how, as society, mitigate or adapt to climate change.

Livelihoods

Mulanje (and Phalombe) districts rank high in terms of human population density (185 people/sq km on average–Figure 3.1) and high rates of poverty and illiteracy. Many people in these districts derive their livelihoods from subsistence farming on less than 0.1 ha of land. Small-scale irrigation agriculture supplements some people's income base and dietary needs. Harvesting and sale of forest products supplement the people's income and livelihoods to a significant proportion of the population living near the reserve boundaries. These include honey, fruit, mushroom and firewood gathering; grass collection for thatch and broom making; poaching and timber production; wild vegetable gathering and medicinal plants, wood carving and ecotourism to a lesser number of people. Water supply from the Mount Mulanje Forest Reserve is perhaps the major resource all communities depend on for various uses, notable amongst which is domestic use and irrigation. Nine big rivers and hundreds of streams supply water to communities below and beyond.

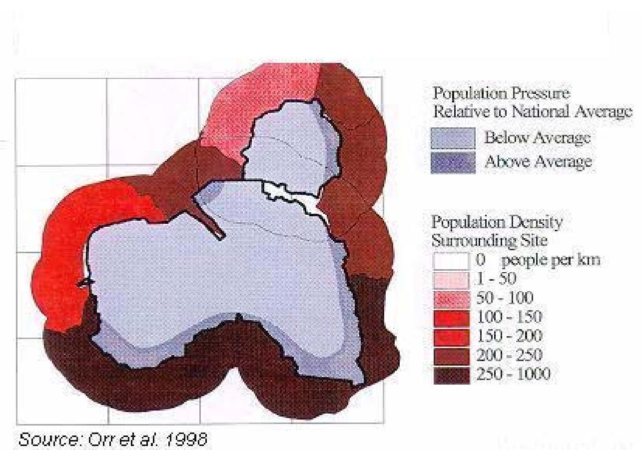

Figure 3.1 Estimated Population Densities around Mount Mulanje Forest Reserve

Climate

Rainfall and climate regimes in Mulanje are and have always been associated with the mountain forest, also partly known to be affected by the Chiperoni Mountains in the adjacent Mozambique. The climate is known to be warm to hot and humid throughout most of the year with annual temperatures averaging 21 to 23^0 C and maximum temperatures around 32 to 35^0 C during November and December. In the dry season during June to mid-August, climate on the Phalombe plains and on the plains south of Mulanje is cooler. On the Mulanje Mountain during the same period, temperatures drop at times to freezing point. The effect of the Chiperoni winds extends well beyond the southern foot of Mulanje. In this zone tea estates are located within several kilometres width, receiving at times dry season rainfalls and occasional mists and fogs. At

Mimosa Tea Research Station (5 km from the mountain and 650m above sea level), the average annual rainfall is 1626mm with 16% falling in the dry season (i.e. May to October).

Resources

Mulanje and Phalombe districts are served by nine (9) perennial rivers. But as communities have observed, some of these rivers are no longer consistently flowing throughout the year as they used to. In the Phalombe area, Phalombe and Sombani rivers drain into the Lake Chilwa Wetland and several tributaries of the Sombani river from the northern slopes of the massif carry water for the greater part of the year. Other major rivers include Thuchila, Likhubula, Muloza, Ruo, Lichenya, Lujeri and Nanchidwa.

Pressures on the land and land-based resources have increased over the past few decades, with the younger potential reproductive age-group threatening the carrying capacities of any natural resources. As a result, per-capita land holding sizes have reduced, land use patterns have changed; in most cases leading to massive soil erosion that lead to silting of the river systems and therefore reduce water flow. Demand for forest-based products has increased beyond imaginable proportions, leading, in most cases, to unsustainable use of the said land-based resources. Forest-based resources include those on which people derive their livelihoods such as grass, timber, honey, mushrooms and water, just to mention a few.

Deforestation in most of the customary lands as well as encroachment in the protected areas particularly the MMFR has resulted in a continued loss of plants and animal life. Forest co-management[1] is just a novel concept amongst the people of Mulanje and it is not yet fully grasped and understood.

Changes in Climate

A desk appraisal, using a number of studies that have been conducted around the MMFR, followed a small Rapid Appraisal exercise in order to put into context local communities' understanding of climate, the cause and impact of climate change in their area over time; and institutional set-ups available that take charge in mitigating climate change issues.

[1] The Government of Malawi's Forestry Policy of 1996 and Policy of 1997 empowers local communities to participate in managing government owned forests.

Community Perception of Climate Change and Impact

C.M. Nansambo, 45, understands climate change as 'the average weather conditions which chiefly depend upon temperature and rainfall'; and H. Manyozo, 43 states '..the difference in weather conditions in a day or over a year and influencing seasonal rainfall patterns and temperature levels'. In all cases, 'these changes often times lead to droughts and incessant rainfalls thereby affecting people's cropping patterns and agronomic calendars, including affecting people's health as evidenced by widespread diseases such as malaria and high blood pressures'. Mussa Chakanja, 56, with 20 years forest experience says "the presence of mosquitoes on high altitudes of the Mount Mulanje (over 1,800m) is enough evidence that temperatures have drastically increased favouring breeding of mosquitoes that cause malaria. From what I can remember, Mulanje district was a mosquito-free area but this is no longer the case'

Malawi's experiences with climate-related disasters are often traced back to the 1991/92 southern Africa drought that caused suffering to over 6.1 million people (Action Aid Report, 2006). Mulanje/Phalombe experienced the worst flooding in 1991 when continuous rains on mount Mulanje and Michesi led to flush-floods that swept across nine villages, destroying life and property; followed by a number of droughts that led to extremely poor crop harvests. The worst of these droughts occurred in 2005.

In spite of a seemingly lack of awareness of climate change amongst local inhabitants, common indicators of climate change are attributed to the little, erratic and largely unpredictable rains coupled with shifting of the on-set of the first planting rains.

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Indicators of Change ~ Temperature and Rainfall

Claims abound that climate change is real and is here. The 1991 flush floods in Phalombe still linger in people's minds and are attributed to climate change. Senior T.A. Mkhumba wonders: "*why from nowhere did these rains come like that, raining for three consecutive days and nights without stopping? What other sign do you need to see to appreciate this is as a result of changing climate?"*

Recent occurrences and observations on the local weather changes/climate have had a number of impacts as well as triggered reactions of a sort. Temperature data from Mimosa Tea Research Foundation [2] shows a steady constant increase in maximum and minimum temperatures, especially during the past twenty years (1986 – 2006; Figure 3.2). Over the longer period, from 1963 to around 1987, average maximum temperatures hovered around 28.5^{0}C, and the period between 1986 and 2006 has seen an increase of over 1^{0} C, averaging 30.0^{0}C. Similarly, the minimum temperatures have also shifted with almost similar margins over the same period.

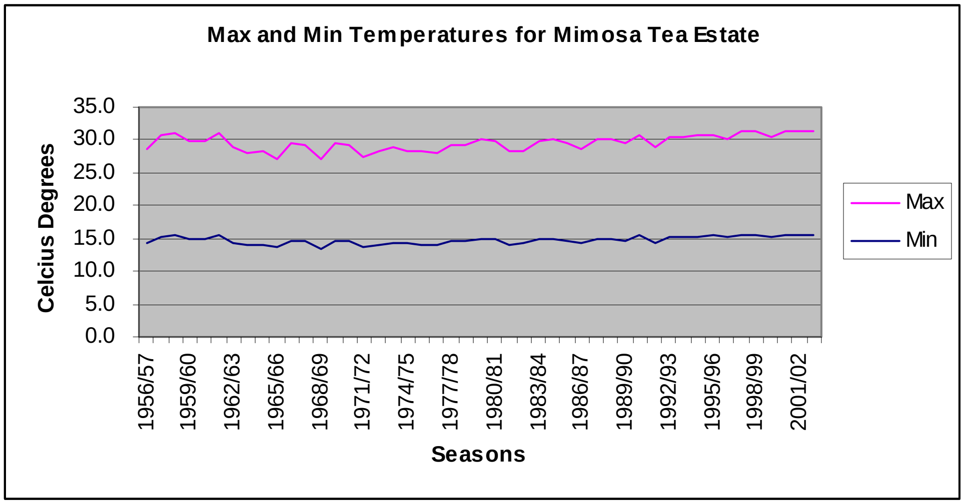

Figure 3.2. Maximum and minimum temperatures for Mimosa Tea Estate

Source: Mimosa Tea Research Foundation

These temperature increases, as evidenced by the erratic rainfalls (Figure 3.3) in Mulanje over the two decades, confirm the claims made locally and at a national scale on climate change.

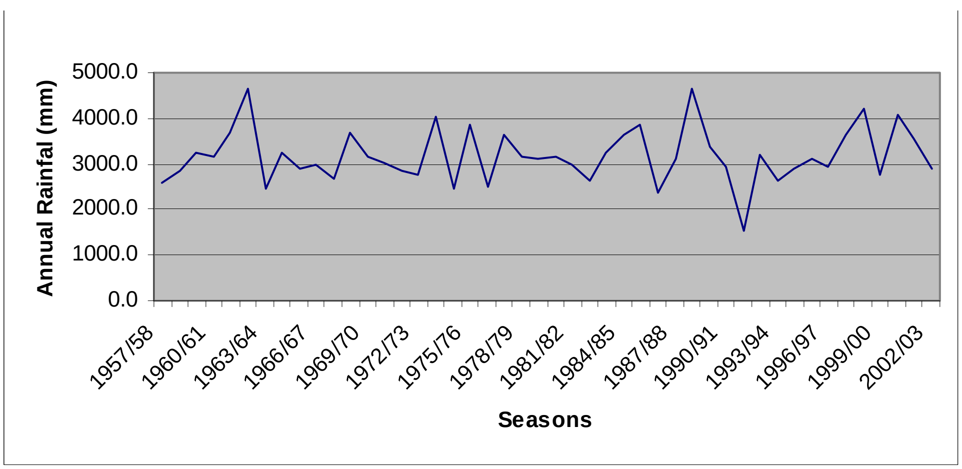

Figure 3.3. Total annual rainfall for Mimosa Tea Estate
Source: Mimosa Tea Research Foundation

[2] A research station that collects climatic data and covers much of the case study area.

Changes in resources (Conditions of water, Agriculture, forests)

The great majority of people's livelihoods in the area depend on agricultural production (through rain-fed small scale farming and small-scale irrigation), wage labour in the surrounding tea estates and forest-based resource harvesting and sale. Forest-based resources include firewood (domestic, for sale, for brick making, and for clay pot firing), charcoal (largely for sale in the near-by urban areas of Blantyre, Limbe, and Mulanje peri-urban centre; building poles, posts and roofing struts, thatching grass, food for subsistence and sale (mushrooms, wild yams, fruits, leaves, honey, small game, birds, and insects), wood for carvings and curios, mortars and hoe handles, bamboo, palm, grass brushes, medicines, and soft timber (Mulanje Cedar) for the construction industry.

Some of these resources are highly sought after, especially the tree-based resources, and the methods of harvesting involve cutting, mutilating, maiming and digging out roots of shrubs. Encroachment into the forest reserves has come about as a result of increased population pressure. It is now common to see people encroaching into the reserve boundaries as well as the interiors where significant amount of forest land is cleared to pave way for farming.

Perhaps the water resources are becoming increasingly a subject of discussion in many community forums. Potable water as well as water for irrigation is becoming an issue on many political forums where both politicians and communities advocate provision of clean drinking water and promotion of irrigation and fish-farming.

Water

It has been noted over time that provision of water to communities has never been a responsibility of government, especially in the rural set-up. Villages dug wells in their nearest vicinities where the water table was always high. Over time, the dug-out wells have often times dried, leaving people with an option of relying on the rivers. But even so, most of the rivers are no longer having a reliable flow as depicted in one of the major rivers (Lichenya; Figure 3.4)

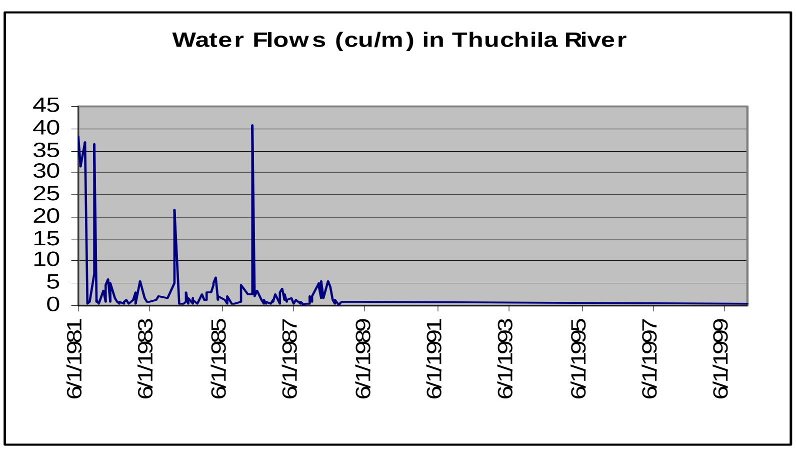

Figure 3.4. Water Flows in Thuchila River

The graph above depicts annual average flows of water in Lichenya River between 1981 and 1999. Although the data has so many gaps due to irregular meter recordings, and a virtual non-recording period between 1989 and 1999, the first segment depicts some sort of flow irregularity, partly because of seasonal fluctuations but evidently with abnormal peaks of roughly three year return period. This in itself however is not conclusive to suggest any climate change influence, but very important to note the three year intervals of abnormal peaks. In most cases, these peaks have followed on a drought year. For instance, Malawi was under a severe drought in the year 1980/81 and another followed almost four years later in 1985 before a heavy fall in 1986.

The above rainfall chart is deficient in many ways, but largely due to inadequate data collection from the rivers around the mountain. This is partly due to inadequate human capacities to carry out regular data collection activities but also due to unavailability of metering devices on the rivers which is a major concern. It is possible however to involve communities to take readings on a regular basis, only if the devices could be provided.

Agriculture

Farming forms part of the economic livelihoods of the people of Mulanje. An estimated 63% of the total land area in Mulanje District is under subsistence and commercial agriculture out of which 70% is under subsistence farming and 30% under commercial farming, largely tea plantations (Figure 3.5). Forests, discounting the Mulanje Mountain forest reserve (MMFR), only take up less than 1% of the total land area. 12% of the total land area in Mulanje is under residential areas (16,563 hectares) and the population continues to rise (on average estimated at 208 persons per sq. kilometre).

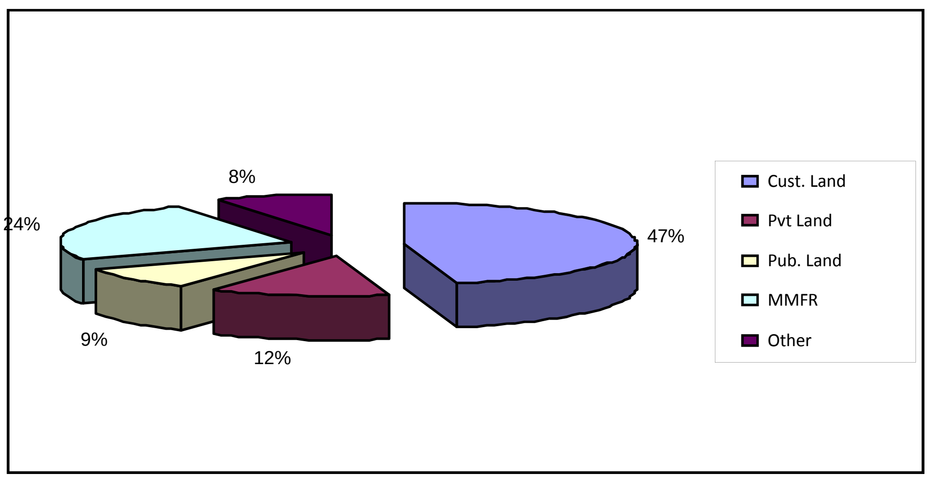

Figure 3.5. Land use system in Mulanje
Source: Mulanje District Socio-economic Profile, 2002

Because of the rapid increase in human population, demand for land and land-based resources is increasing, forcing some communities encroaching into the MMFR. It has been reported that the MMFR boundary has receded more than seven times since being gazetted in 1927.

In spite of these statistics, the MMFR is still regarded as an important landmark that supports life in the district. For many years, the MMFR, assisted by the moist winds from the Chiperone Mountains of Mozambique has been known to regulate temperatures and rainfall patterns of the district. The gazzettement of the MMFR as a protected forest reserve in 1927 was partly to protect this resource as a water catchments and also because of its hydrological cycle role, apart from protecting the rich terrestrial biodiversity. However, as noted by Chakanja and Seveni, the weather patterns are changing, affecting the agricultural calendar.

Forests and Energy

Energy needs and demand for bio-fuel is the major threat to the forests in the district and hence effect on climate change. The 1999 State of the Environment report sites deforestation as the major environmental problem facing Malawi with about 3% of forest cover being lost every year and this figure is now declining because there is not much forest land left to be cleared.

The most common source of energy amongst the rural poor in Mulanje is wood fuel, even amongst some urban dwellers. Firewood is collected in the village, along nearby river banks, in estate plantations and in the forest reserve. While women in some areas sell firewood, if men do collect, they do so exclusively for sale, as an adaptive strategy which largely started in the drought year of 2005. The trend is steadily increasing with the availability of improved road access to Mulanje from the near-by Blantyre city where hydro-power supply is neither reliable nor cheap for everyone's affordability.

Those selling firewood prefer to collect it in the forest reserve, since buyers demand the superior quality of indigenous miombo firewood. Domestic needs are met with virtually anything flammable. Bamboo, eucalyptus twigs, tea prunes, pigeon pea stems and maize stalks are regularly used.

Charcoal production (although not traditionally a livelihood base and energy source for the local Mulanje residents) is becoming widespread. Considering its increased demand in the cities of Blantyre and Limbe, charcoal production is a major threat in terms of its contribution towards deforesting the MMFR as well as depleting other customary land forests. For instance, a study carried out recently has shown that every year, more people are joining the business (Figure 3.6).

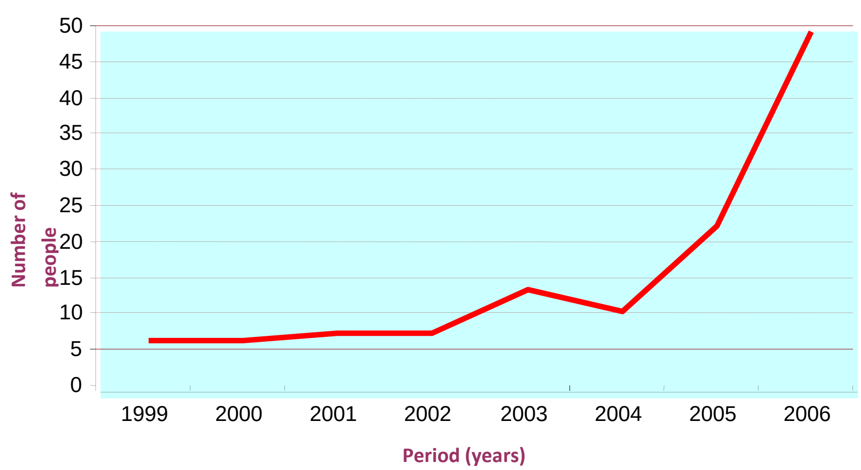

Figure 3.6. Number of people joining charcoal business each year
Source: Charcoal Survey, 2007

Adaptations in Resource Management and Resource Dependence

As a result of the apparent change in weather and climate patterns, communities are aware that instead of a seven month rainy season (October – April), Mulanje is now experiencing shorter seasons, almost always now starting from December and ending around March (approx. 4 months). A number of case scenarios addressing resilience to climate change are here presented:

Water Resources and Agriculture

a) Two important climate change response projects have emerged (unintentionally) in form of 1) T.A Njema Community-based Irrigation Project[3]; and 2) a community-led Chisongoli Catchment and Watershed Management Project[4] also in TA Njema's area. There are several components to these projects (Figure 3.7):

   The irrigation project was initially an individual effort where one farmer diverted Nanchidwa River water through a small water intake to his fish-ponds. The farmer also irrigated his small vegetable gardens around the fish-ponds. As a result of 'small' success he posted, it drew interest from members of the community who joined in, but soon the water supply system (the canal) could no longer provide the much needed water into their fields.

   Through a village committee, they sought external support to build a strong and bigger structure (a weir) to assist in diverting the water, and also improve on the irrigation canal. Today, these communities are happily irrigating a larger piece of land and assisting generating much income from off-season crop sales and fish production in 45 fish farms.

b) The Chisongoli Catchment and Watershed Management project in T/A Njema came about after the realization (by change agents MMCT and COMPASS) that people were encroaching into the reserve and therefore potentially destroying the forest ecosystem and creating a water insecure future for the people down-stream; the major objective being to arrest encroachment into the forest and protecting it from further degradation. Through funding from the United States Aid Agency (USAID) and World Coca-Cola, this project aims to work with communities around the T/A Njema area to withdraw from the encroached forest reserve areas and involve themselves in gainful operatives such as tea growing. Many stakeholders, including the Tea Industry have committed themselves to helping the evicted individuals and other members of the community to establish small-scale tea growing. The Tea industry is raising tea seedlings for distribution to the smallholder farmers and the funding is used to buy such seedlings. All other agronomic activities involving the management of the tea are fully supported by the tea industry through the USAID-Coca-Cola fund.

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[3] A Community-initiated project that is supported with funds from the American Ambassador's Development Fund and implemented in partnership with the Mulanje Mountain Conservation Trust (MMCT).

[4] A Community-based project initiated to rehabilitate and protect the Chisongoli Forest and maintain its ecosystem function of watershed protection, supported by the USAID and Coca-Cola through COMPASS.

(a) Weir cross-section (b) Weir outlet from the gate (c) Canal to be complete

(d) A field ready for second planting (e) Irrigated field with Bean crop

Figure 3.7. Irrigation structures at Njema

c) Because of the rainfall unpredictability, over time communities have tended to respond by employing cultural and farming practices where intercropping and relay cropping have become common practice (Figure 3.8). There is however great potential for the loss of local landraces and genetic pool of crop varieties in the area since most people now prefer expensive but fast maturing varieties of crops such as maize, pigeon peas, cow peas and sweet potatoes. Traditional Authority Nkanda (a woman) observes that not many people grow groundnuts nowadays because the rains are not favourable for the crop. The same applies to other leguminous crops such as cow peas (the local, late maturing varieties), and sorghum, she says, which mature very late in the season and require adequate rainfall. It is also equally impossible to grow late season crops such as pulses and ground beans because a farmer is not sure if the crop will ever get to mature before the rains completely stop.

The positive side of climate change as exemplified above, and according to Mr. Phiri of the Mulanje Rural Development Programme (RDP), (a division of the Agricultural department), the unpredictable rains have triggered a sort of reaction amongst the indigenous inhabitants. The shift to mixed cropping, mixed farming and relay cropping by many farming households in the area is evidence in support of adaptations to climate change scenarios. Farming households are often planting a minimum of two crops in their gardens and such crops are cereals, legumes and pulses and tuber or root crops are included.

Intercrop of maize, pigeon peas, sweet potatoes

Intercrop of Maize, Sorghum, Pigeon peas and Cassava

Figure 3.8. Field Intercropping

Fast maturing pigeon peas (nitrogen fixers and protein sources) are a common intercrop and also fast becoming a cash crop in the district.

d) The development and coming into effect of the Mkhumba Boundary Communities Livelihoods Improvement Project in Phalombe (the drier area of the MMFR) is a collective output from a district decentralized development effort.

The overall objective of the Mkhumba Livelihoods project is to sustainably improve the livelihoods of impoverished communities in Phalombe District who live close to and interact with the MMFR; thereby encouraging the sustainable management of the reserve's natural resources and survival of its biodiversity. The focus is on the boundary communities with the mountain to increase opportunities to harness support and promoting harmony with the MMFR and improve community livelihoods.

With the recognition that T/A Mkhumba is predominantly an agricultural area and that most livelihoods are and will mostly be dependent on farming, trading and processing of farm produce, the project focuses on this aspect with the full understanding of the risks agriculture carries in terms of climate change scenarios (less, unpredictable and excess rains). The action emphasizes on use of wetlands (dambos), small scale irrigation and drought sensitive crops as mitigating measures with an ultimate goal of enabling households to build cash based incomes, some of which can be used for other off-farm related enterprises to reduce vulnerability to shocks that a focus on food security alone will not. The real gains are expected to come from shifting to a livelihoods approach where household income is the focus rather than food production in itself.

e) The tea industry is to some degree and during most of the months (8 months) reliant on irrigation to support the tea bushes to not only provide more harvestable leaf, but also sustain the tea bushes' life during the intense heat of the dry season. In most cases, yield levels have sharply declined over the past twenty year period. Fortunately however, an institutional capacity is available that technically informs the tea growers to adapt to any forms of environmental and agronomic changes – the Tea Research Foundation established in 1966.

Although the birth of the Tea Industry in Malawi can be traced from the establishment of the Thornwood and Lauderdale Tea Estates in Mulanje District in 1891, steady expansion of the industry since that time brought with it the increased loss of the natural forests in order to pave way for the growing demand of arable land.

Because the industry experienced a number of production problems the contribution of scientific research necessitated the establishment of the Tea Research Foundation (Central Africa) formally commissioned in 1966 during which time, there were 13,970 hectares of tea, and the hectarage has increased 200 ha/year on average since then (Central Africana Ltd., 1991). Amongst its mandates, the TRF conducts various plant breeding programmes, including screening of drought resistant teas. In addition, tea estates have increased their capacities to irrigate their crops in order to improve on production and survival of their tea.

Forestry

a) Co-management of government owned forest reserves is a novel concept in Malawi. Since adoption of the Malawi's 1996 Forest Policy and enactment of the Malawi Government Forestry Act in 1997, the concept has only been tried on a pilot basis in the Chimaliro Forest in the central region of the country. In the Mount Mulanje area, this has just started in nine villages, Mbewa village being a case example.

The village (585 households) falls under Traditional Authority Mkanda on the northern-west side of the MMFR and is co-managing a block of 325 ha.

Although farming is the main economic activity in this village, forest products supplement people's daily food, medicine as well as income from the sale of some of the forest produce. Some people earn their living through employment in forest related contract work and tour guiding into the MMFR. Objectives of the co-management arrangement include:

1. To ensure continuous forest cover for soil and water conservation in the area
2. To ensure increased and continued supply of forest products.
3. To enhance production of non-wood forest products such as mushroom, fruits, fibre, and honey
4. To protect the water catchments and
5. To promote tourism.

As one of the products of this community-led initiative, co-management of part of the MMFR has significantly added value to bee-keeping in the area because it has opened up access to the MMFR for hanging bee hives, thereby increasing chances for business expansion and economic wellbeing (Figure 3.9). At the same time, it is becoming evident that the bee keeping opportunity is assisting in the better management of the co-managed area, bearing in mind such a direct benefit to the communities.

One of the beehives hanging in the forest

Women processing harvested honey

Figure 3.9. Beekeeping in Mulanje

b) Demand for energy for cooking and other uses continues to increase, negatively impacting on the environment and natural resources thereby. Firewood sources are becoming less and less and distances to where the firewood can be obtained keep increasing. However, local communities in T/A Mabuka have realized this and doing something about it. A new partnership has emerged to address the problem. Women of Nkuta village requested the Lujeri Tea Estates Company in collaboration with IFSP/GTZ-ProBEC[5] to assist in a project known as Public Private Partnership Program (PPP) with the surrounding villages in various interventions of Biomass Energy Conservation. The activity has brought together eighteen stove producer groups that were initially trained in clay-stove production using a commercial approach. A simple experiment was conducted to demonstrate how this can be done through the use of improved low-cost energy saving stoves (Table 3.1 and Figure 3.11).

[5] IFSP/GTZ-ProBEC is an Integrated Food Security Project funded by the German Technical Co-operation and has incorporated biomass energy conservation initiatives.

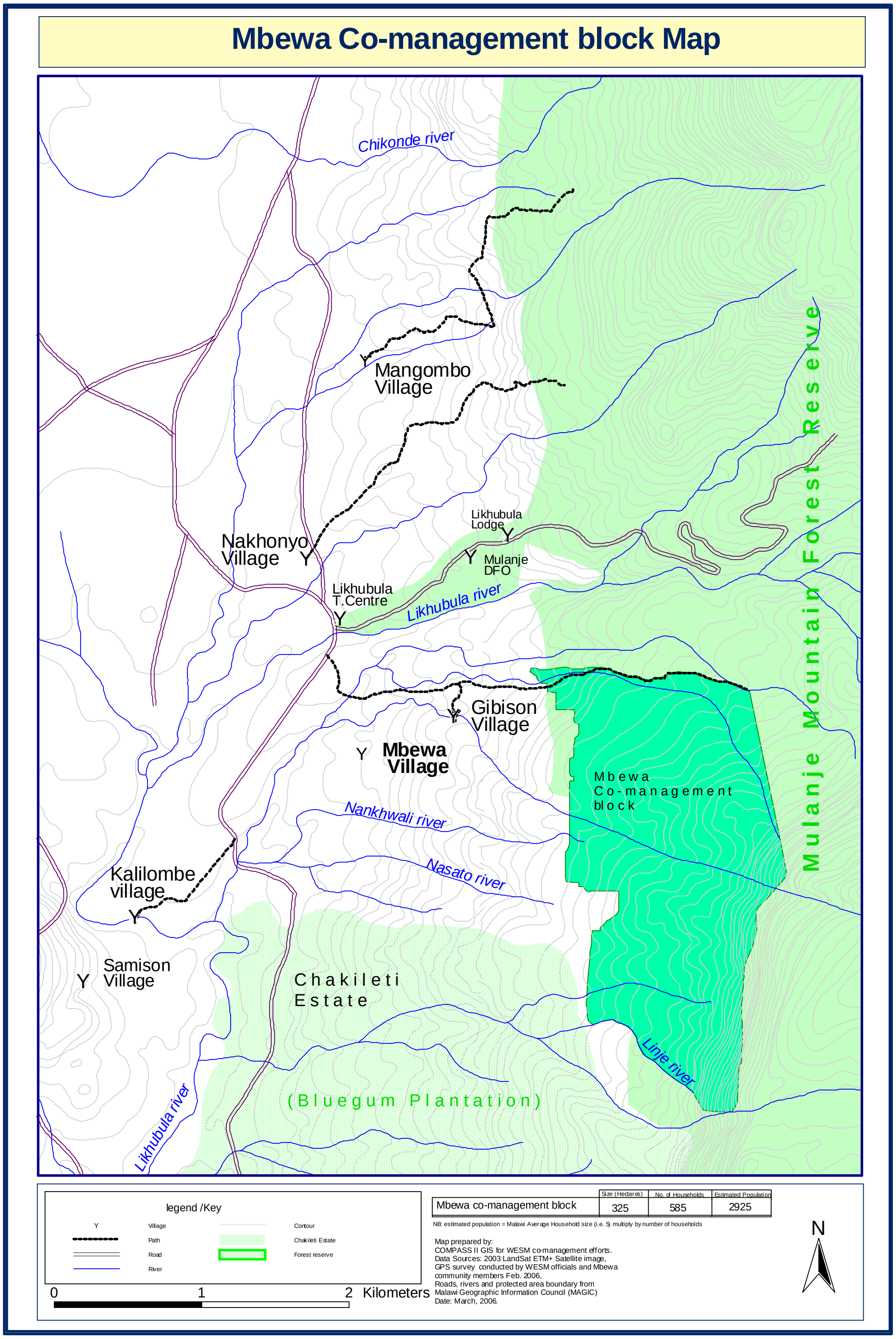

Figure 3.10. Map of Mbewa Village and the Co-managed Forest Block

Table 3.1. Differences between an open fireplace and a clay stove

Open fireplace/ 3 Stone fireplace	**Clay Stove/ Chitetezo Mbaula**
Too much smoke produced	Fire burnt without producing too much smoke
Fire flames flying from all the three sides of the open fireplace.	Fire flames confined within the stove and directly hitting the pot on the fire.
Whole body of the pot completely covered in soot.	Pot had few stains of soot.
Nine pieces of firewood were initially used to set the fire.	Four pieces of firewood were initially used to set the fire.
12 pieces of fire wood were used to complete the cooking process	Only 4 pieces of firewood were used to complete the cooking process.
User could easily feel the heat coming from the fireplace and had difficulties to control the pot due to the flames	User easily controlled the pot as there were no flames coming out from the fireplace

The adoption of the new technology has been on the basis of the following observations which are climate resilience related:

- It is time and firewood consuming to prepare food on an open fireplace because too much smoke (and not heat energy) is generated.
- Clay stoves are appropriate alternative devices for saving firewood when cooking as well as saving money used to purchase firewood and even saving time for going to fetch firewood (hence *Chitetezo Mbaula* literally meaning 'Protective Stove')
- The technology can use any form of wood fuel that is readily available around homesteads rather than depend on forest firewood. It can use cassava stems, tea stems, pigeon peas stems and maize stalks.
- The Chitetezo Mbaula is environmentally friendly and life saver because of its capability to contain heat and protect the user from catching any disease that may come about as a result.

In Mulanje firewood is normally sold in sticks (see photo).

1 Stick of firewood normally costs 13-14 Malawi Kwacha (MK), equiv. US$0.10

In Thuchila trading centre (shown in the photo) and other market places in Mulanje district 3 sticks of firewood are selling at 40 MK, this equals to MK13.33 per stick.

Assuming an average price of MK13 per stick the economy works out as follows:

Saving per meal (only 3 sticks instead of 7= saving 4 sticks)=4 x MK13 = MK52
Saving per day (with two meals per day) = 8 x MK13 = MK104
Saving per month (on the basis of 30 days with two meals per day) = 30 x MK13MK390

Selling price of Chitetezo Mbaula as of June, 2007 = MK150 - 200
Note: Investment pays back in less than 15 days!

Figure 3.11. Economics of using Chitetezo Mbaula
Adapted from ProBEC, 2004 report.

Roles of Local Institutions

Initiatives to conserve the MMFR started some time in 1927 when the reserve was established as a Forest Reserve under Government Act. Because of the unique and in many respects endemic nature of the natural resources in the forest, the Global Environmental Facility through the World Bank funded a Biodiversity Conservation Project in 2002 following pleas from conservation institutions and individuals to protect the natural heritage from apparent extinction. This led to the establishment of the Mulanje Mountain Conservation Trust (MMCT) which, together with the Forestry Department in Malawi established a working partnership. The overall objective was to see a forest reserve that was being managed in a professional and transparent manner and a reserve that is equitably benefiting all. This partnership demonstrates the following shift in the management of the reserve:

The new Malawi Government's Forestry Policy (1996) calls for popular participation of individuals, community groups and private partners in managing forest reserves (Table 3.2). To this end, the many stakeholders have mandate to protect the MMFR in one way or the other, including establishment and management of woodlots and forests in customary and private land. Many of the stakeholders are playing their rightful and positive roles as shown in the case scenarios discussed earlier.

Table 3.2. Past and present policy frameworks for natural resource management

Past	Present
• Centralized and government controlled	• Decentralized and open to NGOs, communities and private sector involvement
• Focus on forest and water catchments protection	• Moving towards ecosystem and biodiversity conservation approach
• Restricted resource use by local communities, largely through licensing and quota system	• Resources sharing and ownership, with focus on value adding
• Policy of exclusion	• Policy of inclusion through co-management arrangements

More important to note at local level is the involvement and active participation of close to fifteen village communities in Mulanje, particularly in the 5 – 7km band of the MMFR boundary. These communities have engaged in pilot co-management activities focusing on a wide range of objectives to address their own social needs. In general, these communities have established what are called Village Natural Resources Management Committees (VNRMCs). Amongst other functions, these committees spearhead environmental and natural resources development programmes, establish by-laws and they set example for others to adopt, as well as engage the wider local community.

The practical reality on the ground in some cases is a more challenging one nonetheless. Experience has shown that some arms of government do not take forest management regulations seriously; as a result, law enforcement has become an issue of much concern at the village level. Culprits of illegal forest related offences do not receive the appropriate punishment that can act as deterrent factors for other would-be-offenders. And because offenders are seen to be favoured by the law, some communities feel frustrated and reluctant to engage in forest protection and management initiatives because of the apparent insecurity over their investments.

The balance of the positives in many ways tilts towards success however, with a lot of communities and other stakeholders coming into play on projects and initiatives that are seen to yield tangible results.

Conclusions and Lessons Learnt

From a local context, climate change might not appear an issue, unless some discussion is initiated. Individuals and communities, although not very much cognisant with the existence and effects of climate change, respond intuitively in various ways. In the foregoing discussion, we have tried to demonstrate a number of community-based initiatives that address climate change related issues affecting communities in Mulanje, particularly those living and interacting with the Mulanje Mountain forest Reserve and surrounds. Of importance are lessons that we draw because of their community focus and what impact the community led initiatives have in addressing climate change challenges whilst improving livelihoods.

1. The T/A Njema Community-based Irrigation Project and the Chisongoli Catchment and Watershed Management Project demonstrate that community initiatives can start from an individual level and that others learn from that. However, it is only from a collective responsibility that something big can be achieved and the collective action can attract external support. It is also possible to have externally initiated actions which can receive support from communities for the benefit of the communities themselves. The obvious opportunities for intervention in terms of mitigating climate change however lie in agriculture and agro-based business initiatives, keeping in mind that the success of such businesses will rely on addressing water supply and management issues. Furthermore, there is need to increase knowledge on the potential for water harvesting and irrigation systems to support agro-based initiatives. In the light of these, there should be a deliberate effort to identify and provide Improved techniques of water harvesting and water management for farmers to effectively use the rivers/streams to help reduce dependency on the rain water for irrigation and to help to increase production for crop with greatest market potential. In addition, in order that the people's livelihoods must be improved, the focus should not only be to create a hunger-free community, but rather promote an enterprise-based community. This will have a multiplier effect of engaging communities in farm-based enterprises which in turn reduce pressures on forest-based resources to generate income.

2. This case study connects the importance of reliable and sustainable flow of water in the river systems to some communities' livelihoods such as small-scale irrigation. The challenge is that there is no reliable data available to assist in determining river flows and how much water can be expected at particular times of the year. There is therefore need to address this gap by helping the department of water to install water gauging facilities in the most important rivers and build local capacities to routinely collect the data (at village level) where water department officials can only assemble this information for analysis and information sharing.

3. The revelation that village communities are increasingly adopting fast maturing crop varieties bred at research stations should provide a wake-up call for all concerned, especially in protecting and maintaining crop gene pool and their wild relatives. Although the fast maturing varieties provide the short term solutions in addressing immediate hunger problems, the potential loss of landraces should not be underestimated. The coming in of the Chitedze Seed Bank in Lilongwe is perhaps a good response to this plight. The institution should therefore cast its net wide to capture all genetic materials for preservation purposes. It should be appreciated though that loss of the crop landraces is a direct consequent of climate change because people have responded to the change by adopting fast maturing varieties. It is important therefore that communities themselves should be encouraged to maintain these landraces by organizing farming communities and providing them with appropriate extension messages that directly address conservation needs whilst promoting climate change mitigation interventions. Furthermore, climate change impact on agricultural production can be minimized if nations and states integrate efforts through institutional and technical capacity building to address matters of common concern. These capacities should be seen to benefit small scale farmers in adapting to climate changes through appropriate information dissemination.

4. The District Decentralization Process needs to be promoted because projects that address the real concerns of the people should be developed with a full understanding of the local situations, with the added advantage that communities and individuals are the best catalysts of development, better placed to identify and address their problems and challenges. Again it has been shown in this scenario that collective action and responsibility can better be harnessed at the district level than where things are controlled from the central government. It is also possible to channel resources through multi-faceted organizations that aim to foster common goals.

5. There are opportunities for non-timber forest-based resources and products, particularly those that can be harvested without environmental damage. Of importance to note is the generalized fact that it is difficult to develop livelihoods around natural resource based enterprises, which do not yet have a viable and existing market. From this vantage point, people-centred management of forest reserves should be promoted from the perspective of improving community livelihoods that supplement agro-based activities. With promotion of other non-tree based resources management in the forest reserves, it is possible to reduce the pressure that the forest reserves are facing, thereby promoting increased forest regeneration and vegetation cover. Through this, climate change factors can potentially be averted. In the same light, when communities realize better returns from managing the forest reserves (such as bee keeping), there is the likelihood that the communities can enforce the law to protect the forests rather than expecting the government department of forestry to do it for them.

6. Lastly but not least, our case study has demonstrated that Private-Public Partnerships can work to the best advantage of mitigating climate change. At a small scale, this initiative is working and should be promoted. The trouble is when many people move into charcoal trading which is the major concern in as far as the Malawi's forests are concerned. The big volumes of charcoal trekking into town make the impact of the above initiative insignificantly effective. It thus requires concerted effort from all sectors of society to identify means to arrest the illegal charcoal dealing.

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4. Coping with Implication of Climate Variability on Household Food Security in Rural Areas: The Case of Rungwe District, Tanzania

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Abstract

Livelihoods food shortage and high downside risk to income is part of life in rural household of the developing countries. Climatic risks, economic fluctuations, and a large number of individual specific shocks leave these households vulnerable to severe hardship. The paper explores the implication and local coping strategies to climate variability on household food security. Climate variability result in food insecurity and there is increasing evidence that the lack of means to cope with food shortage in itself is a cause of persistent variability in living standards and poverty. Climate variability destroys human, physical and social capital and limiting further opportunities. Climate variability is an important constraint on food production and broad based growth in living standards in many livelihoods of the rural communities in developing countries. This paper used survey method in which, household survey, focus group interviews, institutional interviews and participatory observation were used to brings together their voices and perspectives on the implication and coping strategies on climate variability and livelihood food security. In achieving food security and sustainable land resource management, the planned adaptation strategies (for example irrigation, growing drought resistance crops, tree planting, and diversification of economic activities) are imperative. The institution of strategies that provide environment for rural communities to understand possible impacts of climate variability and how they can survive from those impacts is inevitable.

Key words: Coping strategies, Climate variability and food security

Background to the Study

The climate variability has direct and indirect effects on people's lives and development process. The effects depend on location, economic conditions, social systems and issues such as poverty, conflicts, technology, health, and education level. In developing countries, effects of climate change and variability are highly severe because of a weak adaptation capacity (Eriksen, 2001). It can potentially undermine or even retard a country's socio-economic development (Orindi and Murray, 2005).

Farmers in warmer and drier conditions in the Sahelian region of Africa have already shortened their cropping seasons (Hunter, 2007). It has been suggested that yields from rain-fed agriculture are expected to fall as much as 50 percent in some poor African countries. Also fisheries production and natural resources base will likely decline (Hunter, 2007). In the region's drier areas, climate change is expected to lead to increases in soil salinity as well as in soil moisture content thus reducing crop production (Low, 2005). In south and east Africa, previously productive lands will become more arid, and could also see greater desertification (Gwambene, 2007).

The East African lakes: Victoria, and Nyasa have been reported to have warmed by 0.2 to 0.7°C since the early 1900s (Ngusaru, 2007). Also deep tropical lakes are experiencing reduced algal abundance and declines in productivity because of stronger stratification that reduces upwelling of nutrient-rich deep water (Garcin *et al.*, 2006, Ngusaru, 2007; URT, 2007). The East African Rift Valley lakes, recent declines in fish abundance have been linked with climatic impacts on lake ecosystems (Ngusaru, 2007). In Tanzania, over the 20th century, the spatial extent of Kilimanjaro's ice cap has decreased by 80% (URT, 2007). There is annual reductions of water sources since 1976, affecting water availability, along with warming surface waters, deep-water temperatures (which reflect long-term trends) of the large climate change (Ngusaru, 2007). Such effects increase land resources degradation as well as food insecurity (Yanda *et al.,* 2006; URT, 2007).

Rural households in developing countries tend to rely heavily on climate-sensitive resources such as local water supplies and agricultural land (Orindi and Murray, 2005; Hunter, 2007). Such climate-sensitive activities include arable farming and livestock husbandry as well as natural resources such as fuel wood and wild herbs (Olmos, 2001; Pew, 2006; Hunter, 2007). Climate change and variability has reduced the availability of such local natural resources, limiting options for rural households that depend on natural resources for consumption and/ or trade (IPCC, 2001a; Majule *et al.,* 2004; Orindi and Murray, 2005, Yanda *et al.,* 2006, Gwambene, 2007 and Hunter, 2007). Land became less fertile, less local fuel wood for cooking as well as water shortage. Such problems increase demand on land resources, thereby increasing vulnerability to climatic extreme events and food insecurity (Low, 2005).

Study Area

This study was carried out in Rungwe district. The district is among the smallest districts in Mbeya region. It covers 3.5% of the total area of Mbeya region, located on the northern part of Lake Nyasa in southern highland and it lies between Latitudes 8^{o}30' and 9^{o}30' South and Longitudes 33^{o} and 34^{o}5' East (Figure 4.1). It covers a total area of 2,211 km^2 of which 1,658.2 km^2 (75%) are used for agriculture, 44.5 km^2 (2%) for forest and 498.3 km^2 (22.5) for settlement and occupied by mountain. The district located in the windward of the volcanic mountain, which provides the good condition for agricultural production and is among the food producer region in the country. In this area, Lake Nyasa brings heavy rainfall ranging between 2000-3300mm per annum in the highlands (Siegrist, 1993). The wet area is known to be one of the sources of water for Lake Nyasa (Kerl-cross 1891; Siegrist, 1993 and Branchu *et al.,* 2005 in Garcin *et al.,* 2006).

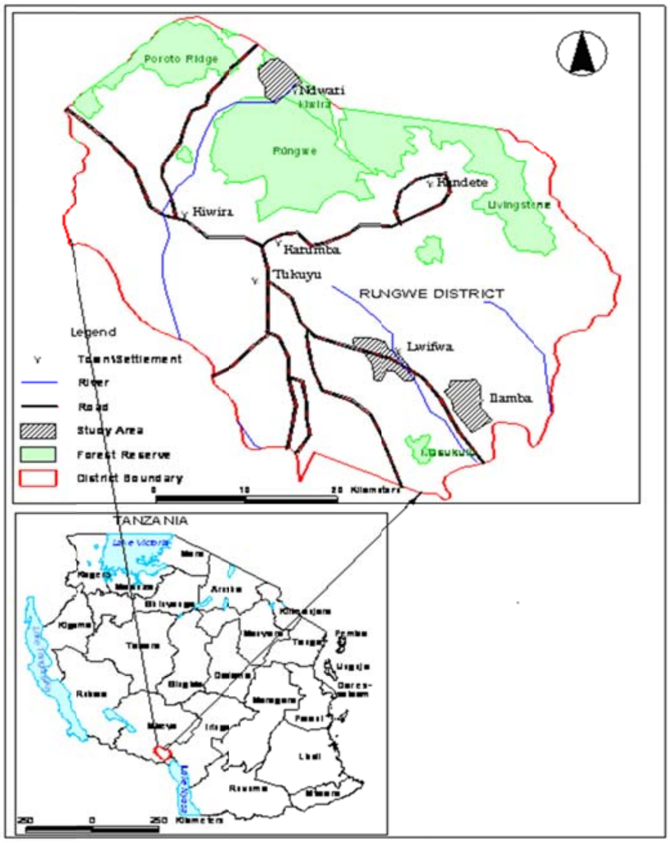

Figure 4.1: Location of Study Area

The district has the vertical landscape gradient with diversity characteristics. It is distinctively divided into three main features that are upper zone, middle zone and lower zone. The study carried out in three wards of the district namely: Isongole, Kisiba and Kambasegela. Isongole ward located at the upper zone, Kisiba at middle zone and Kambasegela located at low zone. The district also acknowledged by climate variability, human impacts on land resources and the sedimentation studies that had showed effects on the lakes from land (Garcin *et al.,* 2006b). This provides opportunity for finding details about this study.

Adaptive Capacity

Adaptive capacity is the ability to cope with impacts of climate variability and change (Smit, 2001 cited in Galvin *et al.,* 2001). Capacity varies among regions and socio-economic groups in that those with the least capacity to adapt are generally the most vulnerable to impacts of climate change and variability (WHO, 2007). Issues of policy, growing populations and low agricultural production, including livestock contribute to adaptive capacity and ultimately, vulnerability (Finan and Nelson, 2001; Little *et al*., 2001 cited in Galvin *et al.,* 2001; Lamb, 1995).

Developing countries are dependent on climatic resources and because of growing populations and lower technological capabilities generally they have lower adaptive capacity (Downing, 1997; Magistro and Roncoli, 2001 cited in Galvin *et al.,* 2001). This is especially true for small holder farmers and pastoral people, who inhabit arid and semi-arid regions with high climate variability (Olmos, 2001). Most adaptations to climate variability are socio-cultural, that is, changes in management which encompass a series of reactive responses to a climate event such as drought (Galvin *et al.,* 2001). Here, as is the case for many developing regions of the world, government organized adaptations are still poorly developed (Kates, 2000). Where public adaptations have been tried, they have been largely unsuccessful.

Theu *et al.,* (1996 cited in Galvin *et al.,* 2001) describe how climate policy in Malawi encourages farmers to grow drought resistant crops, keep smaller livestock herds, and maintain food reserves. These adaptation policies have led to conflicts because maize is the preferred staple food, livestock represent prestige and a symbol of wealth and households require cash for basic needs that they obtain by selling their food reserves. Malawi farmers' adaptive strategies consist of seeking for alternative sources of income rather than altering their traditional food staples and livestock management (Theu *et al.,* 1996).

Factors that Determine Adaptation Capacity

The main determinants (features) of a region's or community's adaptive capacity are: economic wealth, technology, information, skills, infrastructure, institutions, and equity (IPCC, 2001a; WHO, 2007). Adaptive capacity is also a function of current population health status and pre-existing disease burdens (WHO, 2007). Sensitivity, vulnerability, susceptibility, coping range, critical levels, adaptive capacity, stability, robustness, resilience, and flexibility have been used to differentiate systems according to their likelihood, need or ability for adaptation (IPCC, 2001b).

Economic resources: Economic assets, capital resources, financial means, wealth or poverty, and the economic condition of nations and groups are determinants of adaptive capacity (Kates, 2000 cited in IPCC, 2001a; WHO, 2007). Wealthy nations are better prepared to bear costs for adaptation to climatic change impacts and risks than poorer nations (URT, 2007). There is an influence of poverty on a region's coping capacity whereby poor regions tend to have less diverse and more restricted entitlements including lack of empowerment to adapt. Neighborhoods with higher levels of household income are better able to manage vulnerability while poorer nations and disadvantaged groups within nations are especially vulnerable to disasters (Munasinghe, 2000 cited in IPCC, 2001a).

Technology: Technology level, ability to develop technologies, and access to technology in key sectors and settings are important determinants of adaptive capacity (WHO, 2007). Lack of technology has the potential to seriously impede a nation's ability to implement adaptation options by limiting the range of possible responses (IPCC, 2001a). Adaptive capacity is likely to vary, depending on availability and access to technology at various levels from local to national, and in all sectors. Many of the adaptive strategies in management of climate change and variability directly or indirectly involve technology (URT, 2007) example include warning systems, protective structures, crop breeding, irrigation, settlement, as well as relocation and flood control measures.

Information and skills: Human capital or knowledge has great influence in adaptive capacity (IPCC, 2001b). Illiteracy increases a population's vulnerability to many problems (WHO, 2007). Successful adaptation requires recognition of the necessity to adapt knowledge about available options, capacity to assess them, and ability to implement the most suitable options. Adaptive capacity requires a strong, unifying vision, scientific understanding of problems, openness to face challenges, pragmatism in developing solutions, community involvement, and commitment at the highest political level (IPCC, 2001a). Lack of trained and skilled personnel can limit a nation’s ability to implement adaptation options. In building adaptability capacity, there is a need for ensuring systems for dissemination of climate change and adaptation information (ibid).

Infrastructure: Adaptive capacity is likely to vary with social groups depending on the infrastructure used (Pew, 2006). The capacity to adapt to the risk and vulnerability differs between the well-planned settlement or infrastructure and unplanned settlement or infrastructure. Lack of flexibility "in formal housing areas where dwelling form and drainage infrastructure were more fixed" reduces the capacity to respond to contemporary environmental conditions (IPCC, 2001a). Infrastructure can be specifically designed to reduce vulnerability to climate variability, for example, flood control structures, air conditioning, and building insulation general public health infrastructure (WHO, 2007).

Institutions: An institution is a means for holding a society together, giving it sense and purpose as well as enabling it to adapt. Countries with weak institutional arrangements have less adaptive capacity than countries with well-established institutions (WHO, 2007). Countries with well-developed social institutions are considered to have greater adaptive capacity than those with less effective institutions. There is a need for collaboration between public and private sectors to enhance adaptive capacity (Pew, 2006). Inadequate institutional support frequently hinders the adaptation and limits entitlements as well as access to resources for communities, which increases vulnerability to climate extremes. According to IPCC, (2001a) due to inherent institutional deficiencies and weaknesses in managerial capacities to cope with the anticipated natural event, it would be extremely difficult for the country to reduce vulnerability to climate change and variability.

Well-established institutions not only facilitate management of contemporary climate-related risks but also provide an institutional capacity to help deal with risks associated with future climate change (IPCC, 2001a).

Equity: Universal access to quality services, equitable allocation of power and access to resources within a community, nation, or the globe is fundamental in adaptation to disasters (URT, 2007). Adaptive capacity is likely to be greater when access to resources within a community, nation, or the world is equitably distributed. Under-resourced and marginal populations lack adaptive resources (WHO, 2007). The extent to which nations or communities are "entitled" to draw on resources greatly influences their adaptive capacity and their ability to cope (Adger and Kelly, 1999 cited in IPCC, 2001a). The ability to cope with risks also can differ due to demographic variables such as age, gender, ethnicity, education level, and health conditions (IPCC, 2001a).

Adaptive capacity is the outcome of a combination of determinants and varies widely between countries and groups as well as over time (Low, 2005). These determinants of adaptive capacity are not independent of each other, nor are they mutually exclusive. Therefore vulnerability varies spatially because national environments, housing and social structure vary spatially. It also varies temporally because people move through different life stages with varying mixes of resources and liabilities (IPCC, 2001a).

National Adaptation Plans in Africa

Africa is the continent highly vulnerable to impacts of climate change with its people living in extreme poverty (URT, 2007). Mostly, people rely on rain-fed subsistence agriculture, which is one of the climate-sensitive economic activity (IIED, 2006). So, any change in climate has got tremendous impacts to the livelihood of African people. Together with diseases, conflicts (ethnic and political), mismanagement of natural resources, limited human resources, economic and infrastructural capacity, leave the continent vulnerable to climate variability and change (IPCC, 2001a).

Currently addressing adverse impacts of climate change is one of the critical challenges facing the continent. According to IIED (2006), this can be achieved through integrated government planning, partnerships at the local level and with the private sector as well as civil society, and a strengthened multilateral regime at international level in addressing the same needs to enhance the ability to cope with long-term and short-term climate change and variability. Adaptation ability needs integration of planning and strategies to adapt to climate change with research, development and implementation frameworks (IIED, 2006; URT, 2007).

To address current and urgent adaptation needs in Africa, there are international organizations that help to strengthen the adaptation capacity. These organizations help the least developed countries through funding on which countries are required to rank adaptation measures for funding by organizations (NAPA, 2007). The National Adaptation Plans in Africa (NAPA) provides some guidance for the process of compiling a document that specifies priority adaptation actions in the least developed countries. According to NAPA (2007), the NAPA process emphasizes on a participatory approach that involves stakeholders. It is a multidisciplinary approach, and a complementary approach that build on existing plans and programs. It also takes into consideration on sustainable development, gender equity; sound environmental management, cost effectiveness and a country driven approach (NAPA, 2007). The processes must be calculated through simplicity and flexibility based on a country's specific circumstances. In the NAPA process, much of the work of assessing vulnerability and adaptation intended to be drawn from existing sources.

The NAPA guidelines stress the importance of conducting a participatory assessment of vulnerability to current climate variability and extreme events as a starting point for assessing increased risk due to climate change (NAPA, 2007). The main focus of adaptation planning has been at the national level, and has to adequately address all sector adaptation plans. NAPA forms a basis for support not only from the Less Developed Countries Fund under the United Nation Framework Conversion on Climate Change (UNFCCC) as required, but also from the international community at large.

Tanzania's National Adaptation Programme of Action (NAPA)

URT (2007) revealed that impacts of climate change are, and will continue to be more pronounced in poor countries. These countries have contributed the least to the problem and are the least able to cope with the impacts (WHO, 2007). The impacts of climate change on sectors such as agriculture, water, health, energy and others have been the driving force for the preparation of Tanzania National Adaptation Programme of Action (NAPA). The primary objective was to identify and promote activities that address urgent and immediate needs for adapting to adverse impacts of climate change (NAPA, 2007). The focus for Tanzania NAPA was based on adaptation needs in agriculture, water, energy, health and forestry sectors.

Adverse impacts of climate change are evidenced almost everywhere in the country and they pose a serious risk to poverty reduction efforts. Also they threaten to retard decades of development efforts especially the National Development Vision 2025 and Millennium Development Goals (URT, 2005). Thus climate change undermines national efforts to attain the Millennium Development Goals (MDGs) and places poverty reduction efforts in jeopardy. The increased dependence on natural resources, rain-fed agriculture and biomass for household energy can increase vulnerable to adverse impacts of extreme weather events (Majule *et al.,* 2004; Orindi and Murray, 2005; URT, 2007). For example, past trends on droughts and floods as well as recent poor harvests in 2005 caused hunger in most parts of the country (WHO, 2002). Reduction of the ice cap at Mount Kilimanjaro is now more than ever imminent evidence of climate change due to temperature increases caused by global warming.

According to URT (2007) Tanzania submitted NAPA documents to the United Nations Framework Convention on Climate Change (UNFCCC) for funding in realizing the urgency and immediacy of addressing the adverse impacts of climate change. The documents are informed by aspirations of National Development Vision 2025 for high and shared growth, quality livelihood, peace, stability, unity, good governance, high quality education and global competitiveness (NAPA, 2007). The processes of NAPA preparation involve looking at effects of climate change as a threat mainly to the agrarian population.

Tanzania's NAPA deals with identification and development of immediate and urgent activities to adapt to climate change and variability (URT, 2007). It intends to protect people's life and livelihoods, infrastructure, biodiversity and environment as well as mainstream adaptation activities into national and sectoral development policies, strategies, development goals, visions and objectives. NAPA provides public awareness to climate change impacts and adaptation activities in communities, civil society as well as government officials (NAPA, 2007). It assists communities to improve and sustain human as well as technological capacity for environmentally friendly exploitation of natural resources at both community and national levels in a changing climate.

Food Security

Households are food secure when all members have year-round access to amount and variety of safe foods required to lead active as well as healthy lives. At the household level, food security refers household members' ability to secure adequate food to meet dietary needs, either from household production or through purchases (FAO, 1996).

Majule *et al.,* (2004) argued that food security under ecological gradient in which the livelihood systems in rural areas take advantage of ecological condition differs depending on soil, climate, vegetation and socio-economic. In study areas, results indicated that all ecological gradient experienced food shortage as shown in (Figure 4.2). In most case, the food shortage reported to occurs from November to February.

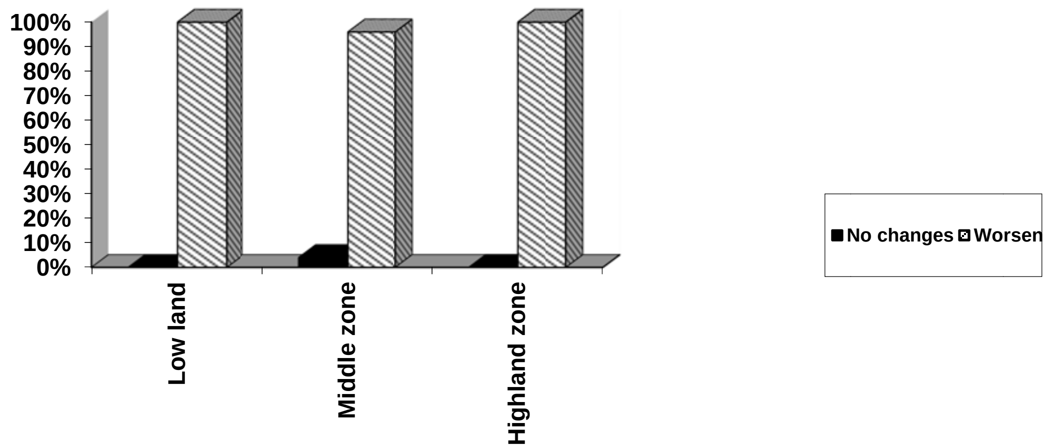

Figure 4.2: Food security across the agro-ecological zones

Basing on household survey 98% of respondents said that food security was worsening while only 2% said there were no changes. The main causes of food insecurity in the area as mentioned by most respondents included climate variability impacts which, include droughts, increase of pests particularly nematode root rot, weevils (banana pests); pod borer, stem and ear borers; armyworms; cutworms; grain moths; and beetles that destroy crops. The current global warming has increased food insecurity, which is associated with increased fungal related diseases due to favourable conditions or increased pest reproduction (Low, 2005).

Poor farming practices were blamed on the cause of soil erosion and soil exhaustion, which in turn result in low harvests. Other causes were an increase in population growth that increased the demand for food and land for cultivation; selling of food without budget for household consumptions for the rest season, poor storage and low crop harvests that contribute to food shortage. Increase of inputs prices especially for fertilizer resulted in low production as most of farmers do not afford to purchase them (reported by 95% of respondents).

According to FAO (2005), there is no food scarcity for those who can afford to buy it. Although the global picture shows aggregate food surpluses and falling prices, food security remains a key concern. This is because millions of people do not have economic access to sufficient food. Poverty is the main cause of food insecurity especially in sub-Saharan Africa and Asia whereby those living in villages are highly vulnerable (abid).

Biodiversity, especially agro-biodiversity, are important assets that favour poor people's food security. But these resources are constrained by current climate variability and environmental changes attributed to human activities. The greatest range and volume of biodiversity has been affected by climate variability and anthropogenic activities leading to increased food insecurity. The right to food is a basic human right, mandated in international law and recognized by all countries (FAO, 2005). Greater efforts are needed to safeguard our land resources to improve food security and our response on climatic extreme events

Climate Variability

Records on environment and climate through the study of sedimentary cores from Lake Masoko (Kisiba), reconstructed changes in various terrestrial and aquatic components of environment as well as climate in Rungwe district (Majule *et al.,* 2007). Those changes were associated with anthropogenic activities and climate change and variability (Garcin *et al.,* 2006a). Basing on weather data, there is a high variation in precipitation and temperature in the district (Figures 4.3, 4.4 and 4.5). Such variation affects farmers in terms of crop production.

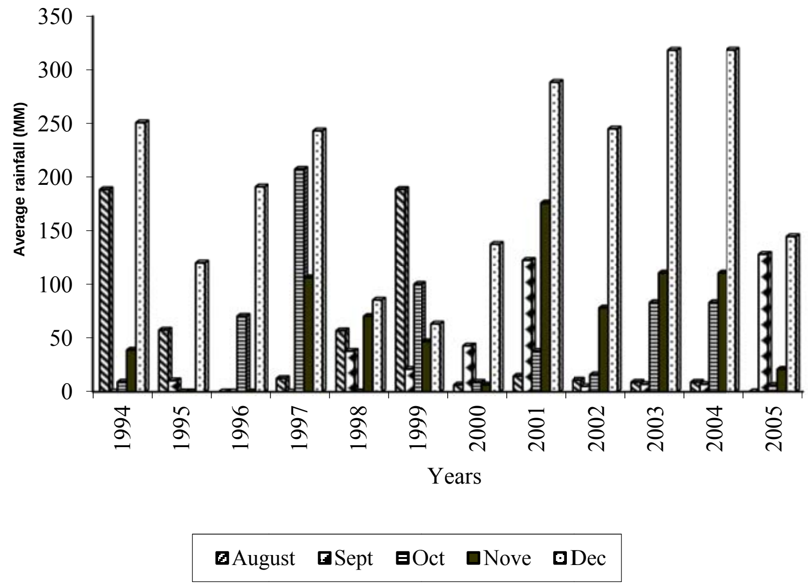

Figure 4.3: Rainfall Variation in August to December (growing season) 1994-2005

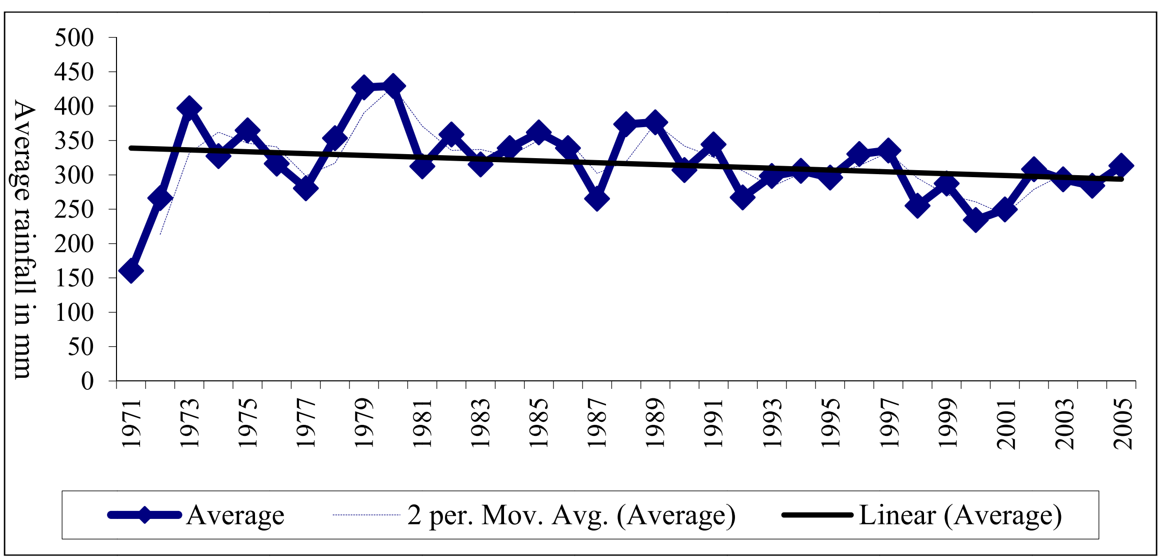

Figure 4.4: Annual Rainfall Variability

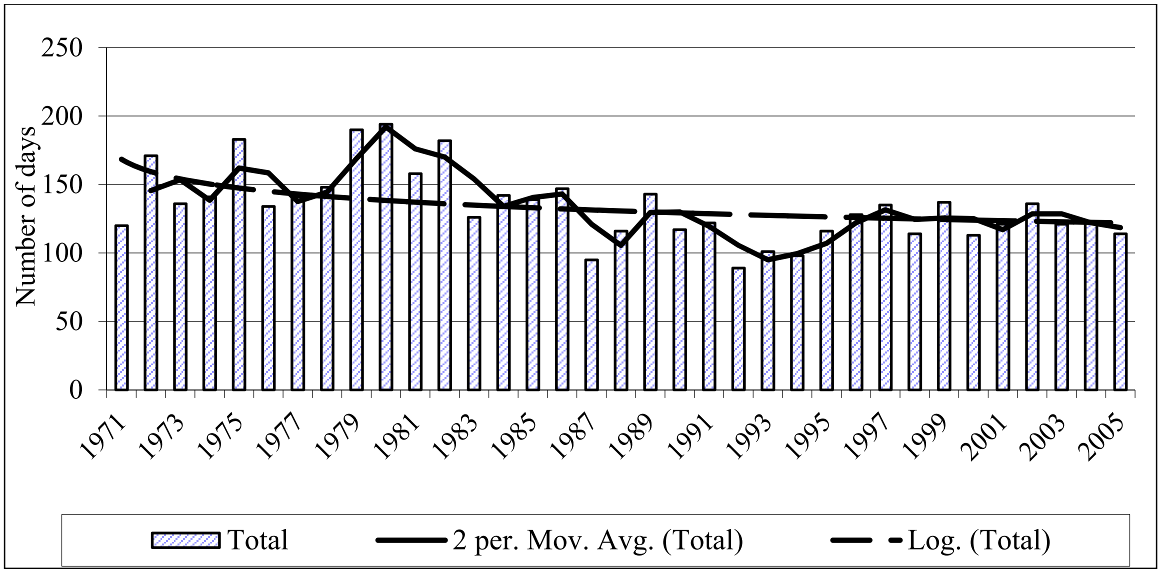

Figure 4.5: Raining Days in Rungwe District

Scientific evidence indicated that climate change in the southern volcanic zone of Tanzania has impacts on vegetation, hydrology and soils, which significantly affects people's livelihoods (Branchu *et al.,* 2005; Garcin *et al.,* 2006a). For example, human influence on environment particularly fire activities is evident in Lake Masoko sediments. It has reported that the impacts of climate change on land use have significant implications on food security.

Rainfall pattern varies from year to year as shown in Figure 4.4 Annual linear average rainfall shows a decrease in rainfall. The decrease in rain has a greater variation in rainfall intensity as shown by *2 per* moving average in Figure 4.4. These variations affect growing seasons and sometimes harvesting seasons. Respondents reported that the effect of rainfall variations is among the main problems in food security and household income.

Analysis of rainfall data over 35 years revealed greater variation in rainfall (Figure 4.4). There is a decline of rainfall intensity with high variation in average and ranges on which 96.6 % of respondents perceived the decline in rainfall while only 3.4% perceived no changes in rainfall patterns. Such variation in rainfall pattern was blamed by many farmers to cause low productivity and increased diseases together with food shortages.

Greater variations in rainfall have been observed from August to December on which the rainfall intensity and the number of raining days change year-to-year (Figure 4.3). This indicates the rainfall variation in growing season, which affects crop production. Farmers used to have rainfall on the early days of November. The rainfall pattern changed and has no common patterns as used to be in past days.

The number of raining days decreases with high variation within years see Figure 4.5. There is a clear indication that change in rain days affects the growing season or pattern that results in less harvest. Such rainfall variations have an implication on food security, agricultural production and resource management. The decline in crop production increases resources utilization and land under cultivation as the response mechanism. Increased natural resources depletion, water sources degradation, deforestation and soil degradation increase vulnerability to impacts of climate change and variability. Normally, changes in raining days have implications on agricultural production in the area since the growing season depends on the rainfall pattern, the delays of rainfall result into late growing season.

The spatial variations in rainfall are not much more but this divides the district into different climatic zones. Its variation in rainfall and temperature divided the district in agro-ecological zones on which different crops are grown. Sometimes zones experience different rainfall patterns that make the district unique in producing varieties of crops. One zone may receive more rainfall while the other received less rainfall in the same year. In the case of food shortage in one zone, farmers used to exchange or buy food to other zone.

Farmer's Perception on Climate Variability and their implication on food security

Farmers being more exposed to impacts of climate variability have a better understanding about climate change and variability. Most farmers in the surveyed areas knew about climate variability and their implications on livelihood. Temperature and extreme rainfall such as heavy rainfall, and drought stand out in farmers' memory of past climate variations. Drought to most farmers is when rainfall did not rain in the expected days or rained just once and stopped. For example, in November, rainfall was used or expected to rain from15th to 20th days but nowadays is not the case. There is increase in rain unpredictability; sometimes rainfall is delayed to December or in more extreme cases, to January as it occurred in 1995 and 2001. Such variability has an effect on agricultural production, land resources management and affects food security.

Farmers often mentioned drought or high temperature, high rainfall and wind. Apparently that was because they could not protect their crops and livestock against them. Some extreme climatic events remembered by most farmers were droughts of 1962, 1963, 1974, 1979, 1982, 1983, 1992, 1993, 2005 and 2006. Others are flooding the following years: 1997, 1998, 2004 and 2005. Some of extreme climatic events that affected farmers are shown in Table 4.1. Generally, there is consistency between farmers' memory of years with high or low precipitation and available meteorological data.

Climate change can bring food shortage and land degradation in different ways, for example *El Niño* causes floods, soil erosion, destruction of crops as well as increases pests and disease, and in addition it destructs infrastructure and reduces crop yield (URT, 2007). These can affect land resources and food security directly or indirectly through human response. Drought affects water availability, causes moisture loss, drying of crops, and vegetation increases pests as well as fungal related diseases that all lead to low productivity (IPCC, 2001a; Low, 2005; Yanda *et al.,* 2006). The variability in raining days affected the growing calendar or and seasons for most of crops. These impacts coupled with unplanned coping strategies that increase land resources degradation and food insecurity.

Table 4.1: Climatic Related Extreme Events, their Impact and Community Responses

Zone	Year	Extreme event	Impacts	Responses
Highland	1970	Drought	Caused hunger, pests and diseases	Food storage, exchange food crops with firewood and buying food
	2005, 2006	Drought	Pest invasion (army worm) and drought of crops	Buying food and crop replacement
	1968,1979, 1983, 1998, 1999, 2005, 2006	Excessive rainfall and strong wind	Destroyed crops and trees, accelerated soil erosion and land slides	Use of chemicals (fungi and pest side for Irish potatoes production), Buying food from other places especially bananas and sweet potatoes from Mwakaleli and Boiling drinking water
	2004	Excessive rainfall	Thunderstorms (death of 3 people)	There were no responses
Middle land	1955,1974, 1979, 1980's, 1989, 2004, 2005, 2006,	Drought	Hunger; crop diseases especially pest and fungi related	Selling part of livestock; exchange crops; growing drought resistance crops and use of chemicals
	1955, 1993,1997, 1998	Excessive rainfall	wiped out ridge; destroyed and spoiled crops, causes outbreak of diseases, landslides and soil erosion, (Wind destroy houses, banana trees, maize and tree plants).	Government constructed new bridge; use of root crop such as yams, cassava, sweet potatoes, and buying food from other areas
Low land	1956,1974, 1975, 1979, 1980's, 1983, 1989, 1993, 1997, 1998, 2004, 2005, 2006,	Drought	Caused food shortage; pest and diseases; dried out of water and crop and increased hunger	Cultivating in wet areas; buying food; receiving help from relatives, and growing new crop
	1997, 1998	Excessive rainfall	Diseases and destruction of infrastructure, crops, loss of animals, and food shortage	Cleaning the surroundings and planting new crops

Coping Strategies for Food Security

In response to extreme events, households and communities develop diverse coping strategies that assist families in difficult period (Table 4.2). Coping strategies are alternative activities in which households engage in order to secure food or income during extreme events (Low, 2005;

Orindi and Murray, 2005). They are necessary for reducing vulnerability, particularly for the most vulnerable communities, region and social groups. Many of traditional coping strategies are short term, but do provide an important lesson for how better one can prepare and adapt to climate change and other extreme events in the long-term. Such strategies differ among households and communities depending on available resources and social capacity of the household, family, society or community (Smit and Pilifosova, 2006). Better achievement is only possible if local people's vulnerabilities, capacities and risks are understood.

Table 4.2. Local Coping Strategies

Short term responses	**Long term responses**
• Selling livestock • Selling forest products (fire woods, Charcoal burning, pole, and timber) • Engage in casual labour • Small business • Buying food • Decrease amount of supper • Not selling food • Receiving remits from relatives • Receive food from relatives • Boiling water	• Garden irrigation • Cultivating in wet areas • Growing drought resistance crops such Yams, Bananas, and cassava • Waiting the grace (take no action) • Storage of food • Tree planting • Contouring • Change crops and growing different types of crops • Not using fire • Not cultivating on steep slops • Growing root crops • Renting wet area in other places • Migrating

Farmers' households engage in diverse activities during extreme weather events which include: receiving remittances from migrant household members; collecting wild fruits and switching to non-farming activities or in extreme cases, selling assets. Other Coping mechanisms during climate extremes include casual labour, petty business, take fewer meals in a day, change in diet, search for loans from traders, brick making, handicraft, collecting honey and charcoal making. Local fruits are highly regarded because they could be harvested by any household member and did well in drought conditions (Orindi and Murray, 2005). These activities provide important sources of cash to allow households purchase food and cater for other necessities at such times.

Remittances from migrant family members and relatives play an important role in household well-being during difficult periods. People who receive remittances tend to be less affected by shocks in terms of access to food, health services and school attendance. Sale of household goods is another strategy, albeit, only for a short-term. Household goods and assets such as land and livestock can be sold to pay off debts incurred during extreme events. This erodes the asset base and, ultimately, on household's chances of long-term survival. Such short-term coping strategies need to be managed to ensure that households do not descend into a state of helplessness.

Coping and adaptation strategies have negative and positive effects on food security and land resources management. For example, use of forest resources such as selling firewood, brick burning, and charcoal making accelerate deforestation as well as land degradation. Some of the coping strategies like receiving remittances, aid and help from relatives or friends are free from negative effects on land resources. Instead they can reduce pressure on land resources. In recent years, migration to urban areas in search for paid employment has become increasingly popular even though urban unemployment is high. However, it reduces labour available in rural areas, as those who migrate are mostly the young and energetic increasing food insecurity. Typically, it is men who move in search for off-farm employment, but overburdens women left behind.

Generally, local people in the surveyed areas had low incomes and food security due to dependence on rain-fed agriculture and inhabit isolated rural environments. These expose them to social problems of economic insecurity, inadequate water supplies and low level of health as well as education standards. Such inadequate social safety nets put them at greater risk of climate variability. A study by McCarthy *et al.,* (2001) and IPCC (2001b) indicated the same situation. The nature of settlement resulted from the nature and types of socio-economic activities such that it increased dependence on nature.

Decline in soil fertility and current climate variability forced people to cultivate larger areas, along wet areas, crater lakes and riverbanks for production. Lack of alternatives to land resources utilization and management is the main problem, which results in poor coping strategies. The increasing fluctuation and shorting price of fertilizer increased food insecurity and vulnerability. The decreasing crop yields year after year, forced most farmers to look for extra land areas beyond their residences in order to sustain their families. These have resulted in land resources degradation and recurring food shortage.

Promotion of drought resistant crops is among the commonly used climate coping strategies in central zone in Tanzania. Such measures have been integrated into national and districts development strategies, multi-sectoral policies, and sectoral policies. Eriksen (2001) shows that the Tanzanian Food Policy emphasized on preventing land degradation and encouraged use of drought-resistant crops including early maturing seeds in marginal areas. In this study, it was revealed that small holder farmers did not adhere to such strategies. Farmers were reluctant to adopt certain drought-resistant crop species. The reasons included low market and consumption values, and the high labour investment associated with cultivating such species.

Successful cultivation of drought-resistant species requires numerous measures to address social, economic and technical constraints (Pew, 2006). In the middle and low land areas of Rungwe district, farmers cultivate bananas, cassava and sweet potatoes as drought resistant crops but they do not grow finger millet. In the highland area, farmers had no alternative crops; instead, they planted trees for cash.

Implication of coping strategies

Coping strategies have to reduce the level of damages that might have otherwise occurred. However, adaptation is a risk-management strategy that is not free from costs or is foolproof (Pew, 2006). Also worthiness of any specific action must carefully weigh the expected value of avoided damages against real costs of implementing the adaptation strategy (Pew, 2006). For human systems, success of adaptation depends critically on availability of necessary resources, not only financial and natural resources, but also knowledge, technical capability, and institutional resources (Pew, 2006; WHO, 2007).

Among the reported common negative implications of coping strategies include soil erosion, loss of fertility, instability of water table, and diminution of water availability. Use of forest resources such as selling firewood, brick burning, and charcoal making accelerate deforestation; natural resources deterioration and land degradation.

The positive impacts of coping strategies mentioned by respondents include increase in food security, water sources protection, and improvement of soil fertility. The majority of respondents said there were minor positive implications of coping strategies, while only 5% of the respondents acknowledged those coping strategies. Some coping strategies such as receiving remittances, aids and help from relatives as well as friends are free from negative effects on land resources. Sometimes remittances can reduce pressure on land resources. The same situations have been revealed by other studies on adaptation (Ning *et al.,* 2003; Pew, 2006; Tsochakert, 2006; Yanda *et al.,* 2006; Watson *et al.,* 2006; Majule *et al.,* 2007).

In exploring factors, which may have contributed to negative implications, 98% of the respondents said poverty and poor farming practices resulted from low level of education level and poor technologies. Other studies showed poverty as the main cause of land resources degradation and food insecurity in most of small farmer households (Kelly and Adger, 2000; Olmos, 2001; Grimble *et al*., 2002). It was revealed that poverty was the main factor that contributed to food shortage and land resources degradation in rural areas. Encroachment on forests and marginal land as well as illegal tree felling for domestic and commercial purposes were an integral part of people's livelihood strategies (Pew, 2006). This was found happening in both surveyed areas, indicating the level of human pressures on land resources.

The mounting loss of land resources from great natural disasters was partly associated with extreme climatic events. Such loss was attributed to lack of appropriate human adaptation/ adjustment and that losses are being increased due to human activities. Poor management of coping activities has direct influence on organic-matter processes in the soil and nutrient fluxes. Also they have a significant impact on soil function. Land use and land use history on given sites influence nutrient dynamics and the potential for erosion damage (Watson *et al.,* 2006; Majule *et al.,* 2007). The short-term changes in the soil water regime and turnover of organic matter as well as related mineralization or immobilization of nitrogen and other nutrients have the greatest effect on ecosystem functions (Fondazion, 1998).

There is a need to improve land resources management practices by increasing adaptation capacity. These will lead to sustainable coping strategies and hence, protecting our land resources and increase food security. Adaptation capacity influences vulnerability of community to climate variability, hazards and starvation.

Response Options

Planning and adjustment of coping strategies requires a substantial improvement in knowledge and experience. Such improvements should include long-term and comprehensive (integrated) programs that promote understanding of land resources, the interactions between social/political structure and functions as well as ecosystem attributes. Control and management options for land use, harvest management, and water quality control are important parameters in land resource management to sustain food security. Ning, *et al.,* (2003) suggested that attention should be on effects and feedback mechanism in the interacting systems of climate, Land resources and human societies. More emphasis should be on evaluation of unusual events (subsequent management pressures) and competing resources. Coping will be viable only if compatible with broader ecological and socio-economic environment. It must have net social and economic benefits as well as take into account stakeholders' participation.

Enhancing household ability to engage in alternative economic activities during extreme climate variability becomes an important measure for improving food security. In reducing vulnerability to climate change and variability, there is a need to reduce the essential needs for households or ensure that harvests fail less often. There are some preferred coping strategies that were successful in enabling households to maintain basic consumption during extreme climate events. However, only a minority of households had access to such strategies. Enhancement of household access to these preferred or principal coping strategies is imperative for food security and sustainable management of land resources

Adaptation responses may be constrained by conflicting short-term and long-term planning. Effective adaptation strategies must reduce present vulnerability as well as future vulnerability to climate change and variability. These measures can contribute to food security, equitable and sustainable policies. Also they are great to present development, decision frameworks and in reducing present day risks from climate variability and by being relevant to immediate national development priorities.

Conclusions

1. Climate variability constrains food security and agricultural development for smallholder farmer's households in the rural areas.
2. Low adaptability capacity to the climate extremes and disasters are the main constrain to the coping strategies and is the cause of persistent variability in living standards and poverty.
3. Poverty limits small holder farmers to have other alternative than utilization of marginal and hazardous land. Such situation increases food insecurity and vulnerability to extreme climatic events and hazards.
4. The current climate variability and decline in land productivity resulted in increase of areas under cultivation to meet household food requirements and incomes. The demands of land for intensification of field meet directly through clearing of vegetation that convert forest and vegetation cover to agricultural land. Marginal land, reserved land, forest, lake craters and riverbanks have been put under cultivation to supplement the degraded agricultural land and for assurance from climate variability impact.
5. The variations in rainfall pattern have resulted on the changes in growing seasons and crops. The land resources specifically soil; water and forest are the most affected through the unplanned adaptation strategies that increase vulnerability to climatic extremes. This made to have no other alternative than to depend on land resources.
6. The frequency of incidence of food shortage has increased in the small holders farmers in rural areas.

Recommendations

1. Efforts to safeguard land resources and insure household food security must be instituted so as to reduce vulnerability to the increased climate change and variability in the district. That would need provision of incentives for diversification and intensification of income and reduce dependence on land resources and risk in agricultural production. It has to promote market access and supplement human capital.
2. In order to achieve sustainable land resource management and insure food security. Agricultural extension officers and other environmental experts must provide education to smallholder farmers on land resource management.
3. There must be public education and awareness rising on effective use of weather and climate information. It will enable farmers to prepare for adverse climate conditions and take advantage of favourable conditions to maximize production. It should be possible by raising the local communities' awareness on climate variability and their roles in land resources management including institutions responsible on managing those resources. There is a need for strengthening soil conservation measures and adoption of appropriate water conservation technologies.
4. Effective efforts in raising the standard of living of the rural community are needed. Poverty alleviation through income diversification and livelihood security and appropriate targeted education could be an important component of future community's development, food security and land resources management.

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5. Utilizing Tree Crops to Reduce Greenhouse Gas Emissions: The Case of Smallholder Farmers with Chronic Food Insecurity in Southern Africa

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Abstract

Global contribution of agriculture to greenhouse gas (GHG) emissions has been estimated to be about 20% for carbon dioxide, 50% for methane and 70% for nitrous oxide. The GHGs are emitted from domestic livestock (methane and nitrous oxide), rice cultivation (methane), burning (methane, carbon monoxide, nitrous oxide, and oxides of nitrogen) and agricultural soils (methane, carbon dioxide and nitrous oxide). Rural family households in southern Africa rely on agriculture for their livelihoods, but food production is often inadequate. The use of fossil fuels contributes huge amounts of GHGs to the atmosphere. Fossil fuel substitutions by bio-fuels has been recognised as a viable mitigation option. For southern Africa, research on bio-fuels should emphasize on the use of tree crops that are adapted to marginal lands rather than field crops, such as maize. The growing of trees, fruits and fodder trees could improve food security and provide a sink for carbon. The use of rapid digestible animal feeds reduce the passage time of food in the digestive system, and hence reduce methane production in the rumen. In this paper, we present some challenges on the use of tree crops to reduce GHG emissions in southern Africa.

Key words: Agriculture, greenhouse gas, crop yield, livelihoods

Introduction

Agriculture dominates the economies of all the countries in southern Africa. This is an indication that the livelihood of many people in southern Africa is dependent on agriculture. For instance, Malawi's economy depends on agriculture. However, there is low crop production and this has affected the livelihoods of many people. There are also many reasons for poor crop performance. Unfavourable climatic conditions has been one of the major causes of crop failure. Such unfavourable climatic conditions will remain a major problem despite the availability of cheap farm inputs. At national level, or let alone at farm level, it would be difficult to reduce the adverse impacts of climate change.

In the wake of unfavourable climatic conditions, crop production has been threatened and this has adversely affected the livelihoods of many people in the developing countries. Central to climate change is the emissions of greenhouse gases (GHGs) into the atmosphere. The main GHGs include carbon dioxide, methane, carbon monoxide, nitrous oxide and the oxides of nitrogen. A balanced level of these GHGs in the atmosphere is beneficial to human beings. However, a high accumulation of GHGs in atmosphere results into unfavourable weather conditions, such as a rise in high temperatures, floods and droughts. This adversely affects food production, especially in countries with fragile economies.

Comparatively, the use of fossil fuels contributes huge amounts of GHG emissions into the atmosphere. However, the reduction of GHG in the agriculture sector is cost-effective compared with fossil fuels. Generally, plants have been recognised as fossil fuel substitutions (bio-fuels) and sinks of GHG. In southern Africa, and other countries or regions, trees (such as *Jatropha curcas*) and other field crops are being exploited as sources of bio-fuels. This is one way of mitigating climate change. However, southern Africa has to make a judicious selection of climate change mitigation measures that would not impinge on food availability. This is because food production is already low and there are also seasonal food shortages in the region. Land holding size, especially arable land for agriculture, has been a limiting factor to crop production. It is envisaged that climate change will impose an enormous constraint on crop production and adversely affect the economic growth of southern African countries. While it is clear that issues of climate change need urgent attention, mitigation measures must be tackled with food security considerations.

Greenhouse gas emissions from the agriculture sector

The contribution of agriculture to greenhouse gas (GHG) emissions has been estimated to be low (20% for carbon dioxide, 50% for methane and 70% for nitrous oxide) compared with emissions from fossil fuels. Carbon dioxide is the major player in climate change issues. The major sources of GHGs from agriculture are domestic livestock (methane and nitrous oxide), rice cultivation (methane), crop residue burning (methane, carbon monoxide, nitrous oxide, and oxides of nitrogen) and agricultural soils (methane, carbon dioxide and nitrous oxide). Carbon dioxide is the main greenhouse gas emitted from the agriculture sector.

Impacts of climate change

Greenhouse gases emitted into the atmosphere are a major cause of climate change, which results in droughts, floods, rising air temperatures and rising sea levels. These are examples of climatic hazards that people in southern Africa have already experienced over the last two decades. For example, there were severe droughts in the 1991/92 and 1994/95 crop seasons, and severe floods during the 1999/00 and 2000/1 crop seasons. In addition, landslides occurred during the 1992/93 crop season due to prolonged torrential rains in southern Malawi. This caused loss of property and life. These are some catastrophic examples of climate change. This indicates that if greenhouse gases are left unabated, they will continue to influence climate change, resulting into more climatic hazards leading to loss of more life and property.

Measures to mitigation climate change

The reduction of GHG emissions and the enhancement of carbon sinks provide both opportunities and challenges for the socio-economic development of any country. Therefore, each country must take a key role towards the reduction of GHGs into atmosphere irrespective of their socio-economic status. It is envisaged that climate change will have an adverse effect on countries with fragile or poor economies. There is a need to exploit the available opportunities by using appropriate technologies in order to mitigate GHG emissions. The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to 'stabilize concentration of greenhouse gas in the atmosphere in such a way that the level would not be dangerous to cause anthropogenic interference with the climate system'. In this paper, we examine the use of trees to reduce greenhouse gas emissions.

Bio-fuels

The production of tree crops for bio-diesel has been promoted in some countries of southern Africa by private organizations, non-governmental organisations (NGOs), and other development partners. *Jatropha. curcas* has been one such tree promoted in southern Africa and many other countries for bio-fuel production. However, there is little information or research on its viability or cost-benefit analysis for farm production although it might have ecological advantages. It is believed that *J. curcas* is less expensive to produce than other energy crops, such as rapeseed and soybeans (Tomomatsu and Swallow, 2007). It is believed that the planting of *J. curcas* is expected to reduce poverty and improve the livelihoods of people in the rural communities as a source of income (http://www.unctad.org, 2005). However, local communities might not achieve the desired rural economic benefits and this could be due to competition with larger plantations unless they operate as farmer groups and are able to extract the oil themselves (Tomomatsu and Swallow, 2007). In view of this, it would be important to assess the benefits that rural family households will achieve by investing in planting *J. curcas* compared with other alternatives. At the same time, it is important to consider issues of food security.

Cost-benefit analysis

Cultivation of *J. curcas* must be based on the cost-benefit analysis since there are no convincing results to indicate its profitability. Furthermore, there are no data to compare its profitability with petroleum products, food or other cash crops. It is anticipated that smallholder farmers could realize profits if they will be involved in both primary (oil extraction) and secondary processing (trans-esterification). Data in Table 5.1 indicate that investing in mango production is more profitable than *J. curcas* production. The revenues derived from irrigated *J. curcas* compare well with mango produced under rain-fed conditions. This suggests that smallholder farmers are better off by investing in some fruit tree production. However, cashew nut and coconut production have lower revenue per unit land. Obviously, if smallholder farmers are to extract the oil and do trans esterification on the farm the revenues per unit land would be high, but the intricacies in these technologies might not be in their favour.

In view of the fact that there are still so many gaps on cost-benefit analysis of *J. curcas*, it is perhaps important to confine its cultivation to marginal lands. The advantages lie in the fact that it is drought tolerant and there are indications that it can be grown on marginal lands.

Intercropping

If *J. curcas* trees are to be grown on smallholder farms, there must be studies to investigate different intercropping systems in order to maximise land productivity. This is due to limitation of land holding sizes per household and food security problems facing many countries of southern Africa. For instance, the growing of fruit trees (e.g., mango and cashew nut) or other field crops with *J. curcas*. There is also some need to select superior germplasm since there is a wide range of genetic variation within *J. curcas* tree provenances for southern Africa. Apart from profitability comparisons of growing *J. curcas* with other crops such as fruit trees, potato, cassava and many others, other environmental benefits must also be taken into account (Tomomatsu and Swallow, 2007). In southern Africa, it might be ideal to promote the planting of *Jatropha* on estate farms, but not on smallholder farmers' fields.

Food crops

Many countries in southern Africa are experiencing food shortage and chronic malnutrition. This is largely due to erratic rainfall attributed to the adverse impacts of climate change, and also due to inadequate farm inputs. The increase in human population is exerting an enormous pressure on arable land, and this does not give smallholder farmers an opportunity to fallow their land. This has contributed to soil infertility. Consequently, crop failure, especially maize, the staple food crop for many people, has been rampart in southern Africa. The use of food crops, such as maize, legumes and sugarcane to produce bio-fuels will definitely worsen the food insecurity problem. Some legumes, maize and sugarcane have been processed into ethanol, but this would impinge on food security of many people in southern Africa. Therefore, technologies that spare the use of food crops in climate change mitigation would ensure food security. This is because a shift by smallholder farmers from food crop production to *Jatropha* is likely to bring an increase in food prices as a result of the reduction in food supply.

Utilization of marginal lands

The use of bio-fuels has been recognised as a measure to reduce huge amounts of GHG emitted into atmosphere resulting from the use of fossil fuels. As southern Africa is exploiting trees as potential sources of bio-fuels, it is important to consider issues of food security in the wake of the limitation in arable land availability. The use of arable land for production of tree crops, such as *J. curcas* for bio-fuels, would reduce the cultivable land for food crops. Therefore, the use of marginal lands would be suitable for the production of such potential bio-fuel trees to avoid competition with food crops.

Fodder for livestock

The use of rapid digestible fodder crops will reduce methane production since this limits enteric fermentation in the alimentary canal of an animal (Moeletsi, 2007). However, this has to considered with respect to its impact on ruminants as they regurgitate to obtain more nutrients. More research is needed to exploit this line of thinking except for ruminant animals. The use of fodder trees/shrubs would support the livestock industry and hence provide the needed proteins to the humans.

Fruit trees

Generally, fruit trees are replaced or cut down after several years. Therefore, fruit trees provide an effective sink for carbon, and hence a good mitigation measure. In some instances, fruit trees are left to grow for twenty years or more with little or no major reduction in fruit yield. The data in Table 5.1 shows that some fruit trees are profitable and also important sources of food to many people. The growing of fruit trees can ensure food security and income generation to many households in the region. It would be advisable for smallholder farmers to invest in fruit trees so as to achieve food security and generate income.

Table 5.1. Cost-benefit analysis of some fruit trees

Crop	Revenue per acre (US$)*
Jatropha (rain-fed)	150 -180
Jatropha (irrigated)	320-384
Mango	347
Cashew	145
Coconut	55

* Production costs are not included in all calculations
Source: Tomomatsu and Swallow (2007)

Wetlands

Wetlands are important natural resources, although they are also sources of natural methane. Wetlands are ecosystems which support the life of many plants and animals. They also act as natural water purification systems, and hence they provide the much needed biological, ecological and socio-economic benefits to human beings. With respect to methane production due to wetlands, which could also be good areas for rice cultivation, it is important that the management of wetlands must be done in a way that minimises GHG emissions.

Conclusion

Countries in southern Africa need judicious technologies, or measures that would mitigate GHG emissions without impinging on food production. Mitigation measures that exploit trees as alternative sources of bio-fuels must be supported as long as they do not compromise food security. It could be advisable for smallholder farmers to commit marginal areas to bio-fuel tree production. Non-food crops, such as *J. curcas* can be used for bio-fuels, but not food crops. More research work is needed to establish the profitability of growing *Jatropha* and its impact on the proposed mitigation technologies on food production.

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6. Impacts of Agroforestry Options in Combating Desertification in Niger

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Abstract

In Niger, since the drought years of 1973 and 1984, the Government, in collaboration with research and training institutes, has carried out works geared towards rehabilitation of degraded lands and combating desertification. Agroforestry options were then developed and disseminated in the country. Many options were tested in this direction such as: farmers managed natural regeneration (FMNR), parkland enrichment, live-fences and techniques for tree pruning and pollarding. These options were accepted and implemented by farmers and have ecological, social and economic positive impacts. More than twenty years later, pilot sites were studied for impact assessment. The results showed that a re-greening (vegetation cover reconstitution) of the village territories is underway with variable tree densities of 100 – 200 trees per hectare, tree crown cover of 25 – 40% and an increase in tree species diversity. Local populations, who were sensitized on climate change and its mitigation through agroforestry, get profit by rational exploitation of trees through firewood and other uses of wood, fodder, human food and medicine and by sales of non-wood forest products. This impact study showed that vegetation is recovering as a result of farmer sensitization on climate change and rehabilitation efforts by using agroforestry technologies. The combined actions of these agroforestry options, together with the approach of joint collaboration of farmers with research institutes and tertiary agricultural education institutions could be a panacea for re-greening arid lands in the Sahel and improving livelihoods of smallholder poor farmers.

Key words: Agroforestry; Desertification; Climate Change, Education, Niger; Parklands; Natural Regeneration.

Introduction

The 1970 and 1980 droughts have led to accelerated degradation of the environment in general and natural resources in particular. The conjunction of recurrent droughts and high demographic pressure on natural resources have literally reduced the production potential, hence exposing the population to a regular non enviable food security situation. Since then, it becomes paramount to inverse the tendency or at least to stabilize the situation for the benefits of future generation, because the risks for production loss are becoming real in Niger. The principal question was to know if actions of recuperation and rehabilitation of the environment could mitigate the degradation process caused by over exploitation of natural resources due to expanding population growth and successive droughts.

With financial supports from various donors, the Republic of Niger has initiated and conducted series of programmes for rehabilitation of highly degraded lands. Many of these programmes were conducted in the 1980s and 1990s.

Twenty years later, the need for assessing the impacts of these investments in natural resources rehabilitation and management became more than necessary. The general perception was that environment in the Sahel and in Niger in particular continues to degrade, that food security is not improving, that rural poverty is increasing, and that impacts of natural resources management projects are limited. Notwithstanding these perceived results, findings from satellite images and aerial photos analysis show that there is a process of re-vegetation taking place at a larger scale, especially in areas with high human densities where populations are engaged in rehabilitation of degraded lands through tree planting and protection.
The objective of the present study was to identify and analyze the impacts of natural resources management (NRM) investments especially their economic and ecological profitability. It tried to answer to two main questions relating to the rehabilitation programmes:

1. What are the main impacts of these investments on production systems, food security, environment and rural poverty?
2. Have these investments been economically beneficial to end-users?

Materials and Methods

This study was carried out in Maradi, Tahoua and Tillaberi, three regions located respectively in the Eastern, Central Eastern and Western parts of Niger, to identify the extent and scale, and also the dynamic and impacts of farmer managed natural regeneration of trees in parklands.
The methodology used consisted in comparing:

- environment in locations with and without rehabilitation projects' interventions,
- within project intervention zones, the situation of the environment before and after the interventions.

From these comparisons, environmental impacts were deducted through evaluation of the evolution of the vegetation cover, biodiversity, soil fertility and water table.

Impacts were also based on agro pastoral productions, population well-being, land tenure security, access to land, emergence and effectiveness of local institutions, effects on national environmental policy as well as economic impacts.

During this study, it was difficult to find control sites as water conservation techniques and farmer managed natural resources (FMNR) were spread out. In total we investigated 16 sites in the three regions (Figure 6.1): 3 sites in Maradi (Dourgou, Dan Saga and Maiguizawa), 9 in Tahoua (Batodi, Guidan Illa, Kolloma Baba, Ourihamiza, Laba, Adouna, Tinkirana, Tama and Garado Nord) and 4 in Tillabéri (Gassikaina, Boukanda, Karébangou and Namardé Goungou). Among these 16, 4 were control sites (Dourgou, Karébangou, Guidan Illa and Garado Nord), 3 were slightly investigated (Ourihamiza, Kolloma Baba and Namardé Goungou) whereas 9 sites were thoroughly investigated (Table 6.1).

For the investigations, various tools were used according to specialty: GIS for aerial photos and satellite imageries, vegetation transects for tree density evaluation, socio economic surveys with farmer focus group and in-depth questionnaires for agricultural production units.

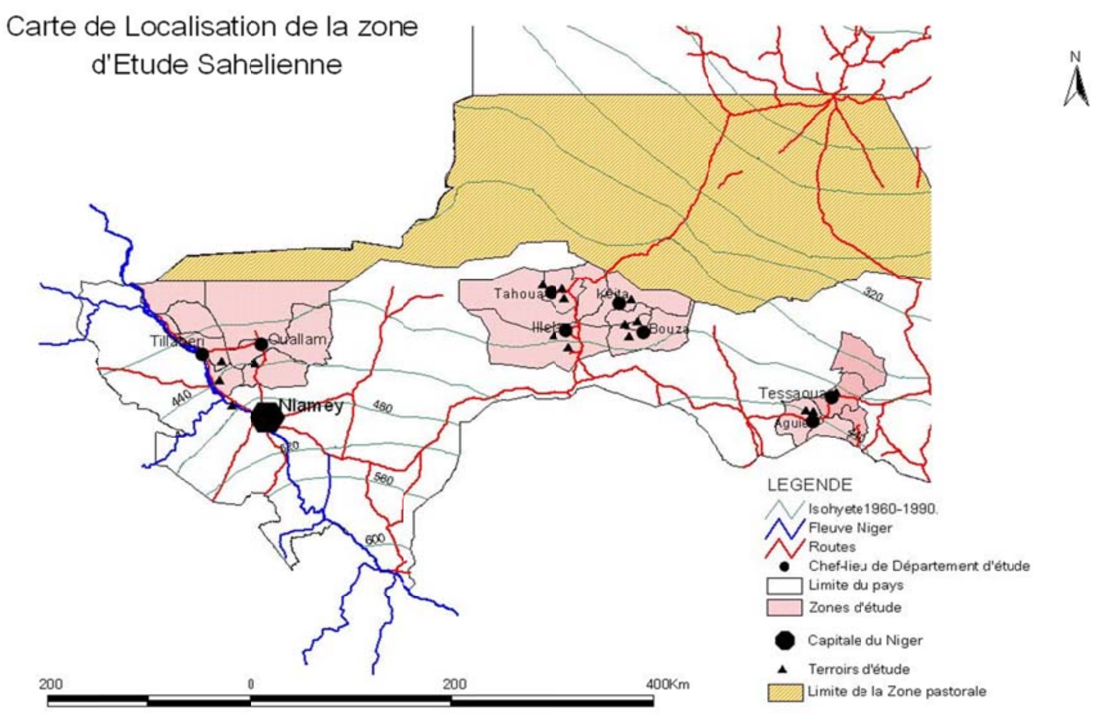

Figure 6.1. Localization of study sites

Results and discussion

Planted trees

Natural Resources Management projects have made tremendous efforts in tree planting in the studied sites. A recent report showed that planted trees amounted to 60 million (Pender and Ndjeunga, 2007). Even if a mortality rate of 50% is considered during the last two years, we could estimate the tree population to at least 30 million. The re-greening of degraded plateau during the 1980s in the Ader-Doutchi-Maggia (Tahoua) is an edifying example. Windbreak plantation in the Maggia valley is another example. On degraded plateau, hard soil surface has to be broken by using water harvesting techniques from runoff (banquettes, planting trenches half-moons, etc) in order to do the tree planting. These are costly techniques but which have given interesting results.

Farmer managed natural regeneration (FMNR)

Besides trees planted by projects or other government services, or small private plantations, an important effort of regenerating vegetation has been carried out by farmers in their fields and this phenomenon has been observed in villages with high population densities. We can therefore say: "More people, more trees". In terms of areas and biomass, the scale of natural regeneration on crop fields is higher than that of artificial plantations. From field inventory and aerial photos analysis and satellite images, areas covered by natural regeneration are estimated to be at least 5 million hectares. The density by hectare (species and diameter classes taking into account) varies from 20 to 120 trees/ha (Dramé-Yayé and Berti, 2007). If an average of 40 new trees by hectare is considered, the number of trees is around 200 million. This showed that the number of protected and managed trees by farmers is far higher than that obtained by land rehabilitation projects..

Table 6.1. Sites investigated

Villages	**Population**	**Number of farmers**	**NRM Intervention**	**Type of interventions**	**Development Projects present**
Dan Saga	2993	215	Yes	Tree plantation and FMNR	PDRAA / PPILDA
Maiguizawa	6047	172	Yes	Tree plantation, windbreak and FMNR	Care International / PAF
Adouna	2416	478	Yes	- Dune fixation Pastoral land tree plantation, windbreak and earth dam	- PDRT - PMET Programme Special du Président de la République
Guidan Illa*	2000	127	No	No	NON
Kolloma Baba	5800	704	Yes	- FMNR Tassa, 1/2moon	PDRT
Laba	6400	1125	Yes	- Tree plantation FMNR	PDR-ADM
Tinkirana	1200	70	Yes	FMNR, Water harvesting techniques and land rehabilitation techniques, tree plantation	PDR-ADM
Batodi	2800	140	Yes	-Tree plantation	-Project FIDA
Tama	6000	500	Yes	-Tree plantation and windbreak	-Care International /PAF
Boukanda*	803	91	Yes	-Tree plantation, Water harvesting techniques and land rehabilitation techniques	PASP
Garado Nord*	5000	243	No	No	Non
Dourgou*	1200	50	No	No	Non
Karébangou	1352	74	No	No	Non
Gassikaina	322	45	Yes	Tree plantation, Water harvesting techniques and land rehabilitation techniques and FMNR	PASP

* Control sites

In the context of this study, an exploratory study was conducted in the region of Zinder, also located in the Eastern part of Niger. This study showed that FMNR is a generalized practice in this region. (Larwanou *et al*., 2006). Farmers have developed parklands on almost 1 million hectares. These parklands were dominated by *Faidherbia albida* with a density varying from 20 to 150 trees by hectare. These re-greening activities were not known to the public outside the involved regions because very few studies were done on them and no publication on them was available. .

Aerial photos and satellite images analysis showed that despite a high increase in human population, there is at present 10 to 20 times more trees than there was 30 years ago. The tree cover increases from 0.6% in 1975 to 16.5 % in 2005.

Tree species diversity

An inventory showed that 56 tree species belonging to 21 families were identified in the study sites. The more represented families were the *Mimosaceae* and *Combretaceae*. The study showed that the richest sites in terms of tree biodiversity are those on project intervention areas. Soil types highly influenced the site capacity to assure plant species regeneration. Globally, plant biodiversity varied according to sites, with on average more biodiversity observed in sites with project interventions. Herbaceous plant diversity was high in all sites. Sites which were completely denuded before project interventions have now more than 100 different herbaceous species. This confirms that water conservation and land rehabilitation techniques enhance plant diversity.

Changes in soil fertility management

Degraded land rehabilitation projects have introduced on a larger scale runoff water harvesting techniques (Zai, half moon, banquettes and trenches) which have broken hard denuded soils to increase their water storage capacity to reduce runoff. Farmers have increased fertilization efforts in their farms. In 1980, few farmers used organic manure on crop fields; the available manure was only being used on irrigated lands. In 2005, at least 80% of interviewed farmers used organic manure in their cereal fields. Most of the farmers who invest in rehabilitating their lands used organic manure. On sandy soils, vegetation regeneration translates a reduction of wind erosion and the availability of litter to fertilize soils. Parklands development has contributed to increase organic matter in farmers' fields especially where *Faidherbia albida* dominates (Larwanou *et al.,* 2006). A positive change in soil fertility was perceived through:

- Progressive smoothing of soil through tassa and half-moons techniques.
- Litter fall and decomposition, and capturing in the soil of small organic materials brought in by the wind, especially where agroforestry practices are developed.

In areas where NRM projects intervened, 40% to 100% of interviewed farmers think that there is an improvement in terms of soil fertility increase therefore, increasing agricultural production.

Projects impacts on erosion control

Erosion control was one of the most important activities for most of the development projects in the Sahel. Farmers do appreciate positively the role of various techniques on erosion reduction and control. In areas where NRM projects have acted, water and wind erosion has been reduced by 30% or more. Reduction of soil loss was also appreciable and depended on techniques.

Impacts on water infiltration

Used techniques have reduced water runoff and favored its infiltration. The excellent performance of tassa technique and crop residues disposal (Ambouta, Moussa and Daouda, 2000), and for half-moon (Evequoz and Guéro, 2000) on soil hydrological regime could be explained by the improved action of the techniques on soil physical and chemical properties. Therefore, organic matter use in terms of crop residues, organic manure in tassa and half-moon holes, stimulate termites' activities which could lead to good soil aeration. In-situ measurements have shown that techniques such as the half-moons conserve capillary water that helps the plants survive for 2 – 3 weeks through drought periods.

Effect on biomass availability

In Niger, the confection of water harvesting and land rehabilitation techniques is of high importance to guarantee a sustainable exploitation of agricultural and pasture lands. Results obtained by some NRM projects are convincing and have shown positive impacts on degraded lands. The biomass production passes from zero to more than 600 kg of dry biomass per hectare after rehabilitation. There is dominance of herbaceous species like *Eragrostis tremula* which has high fodder value and contributes to household economy. In all the sites, farmers have developed techniques for harvesting and conservation of this particular species which is commercialized during dry season. Income generated from sale of *Eragrostis tremula* is used to buy cereals, clothes, medicines and other taxes.

Effect on Charge capacity for fodder

Improvement of fodder availability leads to increasing animal stocks in various villages. The equilibrium livestock needs – fodder availability - have improved significantly following various project interventions. If the practice of water harvesting and land rehabilitation techniques leads to changes in the mode of access to pasture lands, this negative impact could have been largely compensated by positive effects of reinforcement of the charge capacity and opportunistic management of pasture lands.

Economic benefit of water conservation and land rehabilitation techniques

Sahelian countries which are not well doted by nature in terms of natural resources will always be confronted to climate related difficulties. There is therefore a choice to either invest in NRM to stop or reverse the degradation of productive potential or ignore the problem and lose the agricultural lands of the country. The agricultural sector in general (livestock, crops and environment) depends largely on natural resources. Besides direct monetary impacts, investments in NRM have also indirect impacts.

After establishing partial annual budgets for each technique of NRM, the actual net value of investment for various techniques has been estimated based on the duration of the work and initial input (Table 6.2).

Table 6.2: Cost and annual monetary revenues by hectare per technique

Techniques	**Initial investment/ha (FCFA)**	**Additional annual cost/ ha (FCFA)**	**Annual additional monetary revenue /ha (FCFA)**
Tassa	50 000	33 000	77 680
Agricultural half moon	100 000	33 000	79 904
FMNR	24 000	1 000	5 580
Tree planting	60 000	0*	1 473*

Source: survey data and authors estimations
*there is no additional costs if the plantation was done in rainy season. Annual additional revenue is 1473 FCFA for the first 4 years. It is of 10473 FCFA if trees start giving wood.

Another essential element for estimations is the time value which is captured in the actualization rate. Lowenberg- De Boer *et al.* (1994) mentioned that because of the capital scarcity in rural areas in the Sahel, and taking into account profitability rate of certain investments in non-agricultural activities, the actualization rate of activities should be 50% or more. For the current study, the following actualization rates were used: 10%, 25% and 55%. A sensibility analysis was therefore conducted with rates of 15% and 100% in some cases.

Economic Benefits of FMNR.

From the first year of practicing FMNR, light firewood is collected from pruned branches. From the second year on, cut branches can be sold. As wood availability increases, value added products such as hut roves and tool handles can be made and sold for additional income. In a twelve-year period, it was very conservatively estimated that US$ 600,000 worth of wood was sold as a result of practicing FMNR in 100 villages in Maradi Department. Conservative values for income generating potential can be easily calculated:

Area: 1 hectare
No. Trees protected: 40/hectare
No. stems protected per tree: five stems/stump

If the farmer prunes 5 stems on each of the 40 stumps per hectare and harvests only one stem per stump per year, always encouraging a replacement, by the 6th year, she/he could have an assured annual income into the future in the order of 70,000 CFA (US$ 120/year) (Table 6.3).

Thus, over a six year period, a farmer could earn over $512, and $ 140 per year per hectare. This might be seen as insignificant, but put in the Nigerien context where most families hardly earn twice those amounts and use all their income to buy food.' The figures used in the calculations are also deliberately low and account is not made of other benefits such as increased crop yield under FMNR (At least 2 times yield increase), wood trimmings used for home consumption, fodder value of leaves and pods, food items etc. When wood is converted into hut roofs or tool handles, the monetary value is higher than that of firewood. Additionally, leaving 40 stems per hectare is a minimal amount. Some farmers are leaving up to 200. They may not leave all 200 for the duration of a six year period, but they do benefit from harvest and sale of a larger volume of wood each year.

Table 6.3. Projected earnings from prunings over a 6 year period

Year	Stems Pruned	Income
Year 1	40 stems x 0.10 cents	$ 4.00
Year 2	40 stems x 0.70 cents	$ 28.00
Year 3	40 stems x $1.50	$ 60.00
Year 4	40 stems x $ 3.50	$ 140.00
Year 5	40 stems x $ 3.50	$ 140.00
Year 6	40 stems x $ 3.50	$ 140.00
Total		**$ 512.00**

[$1.00 = 500 CFA]

Some farmers do not have much land at their disposal. In West Africa, there are millions of hectares of 'common land' and grazing land gradually degrading and becoming less and less productive. With a participatory approach which includes all stakeholders (farmers, nomadic herders, men, women, youth etc), it would be possible to achieve important results on such areas. The tree regeneration on the areas now under FMNR is even more spectacular when one realizes that in 1983 much of the area was completely cleared. In Maradi, only twelve farmers were tentatively practicing FMNR on as many hectares. In 1984, due to famine, some 500,000 trees were managed through FMNR in approximately 100 villages. This increased to about 2,000,000 trees in 1988 through a second food for work program. Beyond 1988, FMNR took on a life of its own and has spread across the country, through other Non-Government Organizations, Farmers groups, Peace Corps and through Maradi Integrated Project Staff and farmers visiting new areas across the country and sharing their experience.

Conclusion

In the study areas, at least 250.000 ha of highly degraded lands have been recovered through NRM projects and almost 5 million of ha have been regenerated through FMNR. Investing in NRM could lead to combating desertification and the impacts of the various techniques and technologies could help adapt and mitigate the effects of climate change and also contribute to the attaining many the Millennium Development Goals. Farmer's capacity to adapt to ecological crisis such as drought and climate changes has been underestimated. They developed their techniques but helping them with new ones could stream up the actions. In economic point of view, it is rationale to invest in NRM projects and provide technical backstopping to farmers for rural poverty reduction, environmental improvement and acceleration of economic growth. Notwithstanding all these efforts, a lot remains to be done in order to win the game.

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7. The Role of Agroforestry in Mitigating Climate Change in Southern Africa

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Abstract

The predictions of different models on the future effects of climate change on agricultural production in southern Africa point to a reduced and unpredictable rainfall patterns, shorter crop growing seasons, and prevalence of a warmer and drier climate. Given that agriculture in the region is mostly rain-fed, and coupled with the uni-modal rainfall regime and a short growing season, the impact of reduced rainfall will be particularly pronounced in the region. The combined effect of these changes and the current rising trend in world food prices will lead to a significant reduction in maize production which is the staple food in the region, leading to widespread hunger and malnutrition. Smallholder farmers will be the worst affected. Climate change is now being seen as a major threat to global peace and security and its worst negative impact is Africa. Agroforestry technologies offer viable options to cushion against the shock on the smallholder farmers' livelihoods. Soil fertility enhancing agroforestry technologies are associated with increased soil organic matter content and hence conservation of moisture and efficient water use. Fruit trees being promoted also offer real opportunities for diversified income streams and serve as sources of nutrients particularly for malnourished children. A significant number of browse fodder trees are drought tolerant and in drought years can provide the much needed protein source in livestock rations. In addition, trees are capable of sequestering substantial amounts of carbon in their biomass, thus mitigating the impacts when managed at a sufficient scale. The increased adoption of these agroforestry technologies in southern Africa offers a real opportunity for mitigating against the severity of climate change effects in the region. In this paper, we synthesise the state-of-art knowledge on the role of agroforestry in mitigating the adverse impacts of climate change.

Key words: Climate change, Agroforestry, maize yield, livestock production, smallholder sector, southern Africa, livelihoods

Introduction

There is now widespread acceptance that the climate in southern Africa will be hotter and drier in the future than it is today. It is acknowledged that if greenhouse gas emissions are not reduced, global temperature will probably rise by between 2 and 3 °C over the next 50 years, leading to climate changes that will impact food production, health and the environment around the globe. This scenario is already evident in southern Africa where rainfall is becoming less and less reliable and the frequency of droughts is rising. Because the economy of the region is agricultural based, failure of the rains in any particular year will lead to famine, and with the frequency of droughts now on the increase, the region is facing entrenched and widespread poverty, particularly under the smallholder farming situations.

The national governments in the region are well aware of these climatic change trends. The regional grouping, the Southern Africa Development Community (SADC) has responded by setting up early warning units that issue alerts to help member countries prepare for the prospect of droughts or flooding and consider ways of mitigating their effects (Kandji *et al.,* 2006). These countries have also gone further and developed Initial National Communications (INCs) to the United Nations Framework Convention on Climate Change (UNFCCC) proposing various adaptive strategies that they will employ in mitigating and adapting to the adverse effects of climate change. Among others, the strategies focus on the development of irrigation infrastructure, the growing of drought tolerant crops and promoting conservation agriculture.

This paper looks at the potential role of agro-forestry in mitigating climate change effects in southern Africa. The results presented are drawn from the work conducted by the World Agro-forestry Centre (ICRAF) southern Africa over the last two decades. The agro-forestry research work has concentrated on the technologies of soil fertility, fuel-wood, fodder and fruit trees. It is argued that these technologies can be part of the solution contributing to climate change mitigation by providing agricultural technologies that can buffer extreme events, and through carbon conservation, sequestration and substitution. The paper concludes by presenting the number of farmers currently practising agro-forestry technologies in the region and proposing the way forward on what needs to be done to reach many more farmers with the technology.

Predictions on Climate change in southern Africa

According to the Intergovernmental Panel on Climate Change (IPCC, 2001), temperatures in the southern African region have risen by 0.5°C over the last 100 years. It was also noted that below average rainfall was becoming more frequent. Between 1988 and 1992, over 15 drought events were reported in various areas of southern Africa. There has also been an increase in the frequency and intensity of El Niño episodes. The El Niño phenomenon is associated with the occurrence of floods, droughts and frosts resulting in reduced crop yields, the displacement of people and the destruction of assets and infrastructure.

There is widespread acceptance that the climate of southern Africa will be hotter and drier in the future than it is today. By 2050, average annual temperature is expected to increase by 1.5-2.5 °C in the south, and by 2.5-3.0 °C in the north compared with the 1961-1990 average (Ragab and Priedhmme, 2002). The temperature rises will be greater in the summer than in the winter.

From the model outputs obtained by scientists from the US-based National Centre for Atmospheric Research (NCAR) and the National Oceanic and Atmospheric Administration (NOAA), there will be dramatic warming of the Indian Ocean in the future, which means more droughts for southern Africa.

Implications of climate change on agriculture

An increase in the El Niño events have resulted in a decrease in agricultural production, thus worsening the food production in the region. Normally, the heavy rainfall associated with El Niño leads to the water-logging of the soils, leaching of soil nutrients and the proliferation of agricultural pests and diseases. Since 2001, consecutive dry spells in some areas of southern Africa have led to serious food shortages. For example, the 2002/03 drought in southern Africa resulted in a food deficit of 3.3 million tonnes with an estimated 14.4 million people in need of assistance. Kandji *et al*. (2006) reviewed future climate change, its effects on crops and the various adaptive strategies proposed by the southern African countries: Botswana, Lesotho, Malawi, South Africa, Swaziland and Zimbabwe. This information is reported in these countries' Initial National Communications (INCs) to the Conference of Parties (CoPs) of the United Nations Framework Convention on Climate Change (UNFCCC).

In summary, it is predicted that the southern African region will experience reduced and less reliable rainfall regime, increased warming, shifted precipitation patterns and a warmer climate. These changes are predicted to result in a decrease in crop yields due to crop destruction. The governments have generally proposed the growing of drought tolerant crops, changes in planting dates, spacing of crops, planting other different crops, changing the crop location, emphasising more on irrigation and implementing conservation agriculture.

Crop failure in semi-arid areas is often due to poor utilisation of rain-water by crops, especially when the soils are highly degraded. The next section looks at how agro-forestry can make a contribution in mitigating the severity in crop yield reduction in the future.

Role of agroforestry technologies

Agro-forestry by definition is "a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels". ICRAF in 1987, entered into a strategic partnership with the governments of Malawi, Tanzania, Zambia and Zimbabwe to create the Agro-forestry Networks for southern Africa (AFRENA) to promote agro-forestry technologies.

The Agro-forestry technologies are arranged either in simultaneous or sequential systems with crops. Some examples include: (i) the *Gliricidia sepium*/maize intercropping technology, (ii) the improved fallows (IF) technology, which is largely implemented with *Tephrosia* and *Sesbania* spp, (iii) fodder banks and woodlots. Fruit trees are being promoted in different smallholder farming systems in southern Africa.

The major agro-forestry benefits are socio-economic and environmental in nature. The socio-economic benefits include improved food/nutrition security, improved income and the empowerment of women. The environmental benefits include reduced siltation of water bodies, reduced land degradation and desertification, biodiversity conservation, eco-tourism and climate change mitigation.

Soil fertility

The major soil fertility enhancing agro-forestry technologies being promoted in southern Africa include improved fallows, principally with *Sesbania sesban* and *Tephrosia* spp. and *Gliricidia sepium*/maize intercropping. In improved fallows, the *S. sesban* or *Tephrosia* is sequentially rotated with maize to improve yields of the cereal crops. The efficiency of improved fallow and intercropping agroforestry technologies in contributing to soil nitrogen is well documented (Akinnifesi *et al*., 2007). For example, in Malawi, pruning *G. sepium* 2 to 4 times per year, gives annual leaf biomass of 2-7 t/ha, adding between 60-120 kg N/ha to the soil annually. Maize yields can increase by 343% from 0.94 t /ha in unfertilized sole maize to 4.17 t/ha in *Gliricidia*/maize intercropping.

Phiri *et al.* (2003) studied water balance dynamics in Chipata Zambia following *S. sesban* improved fallow practice. Soil balance were assessed for maize following 2-year *Sesbania* fallow and in continuous maize with and without fertiliser during the 1998/99 and 1999/00 crop seasons. *Sesbania* fallow increased grain yield and dry matter production of subsequent maize per unit amount of water used. The average maize grain yields following *Sesbania* fallow and in continuous maize with and without fertiliser were 3, 6 and 1 Mg ha^{-1} with corresponding water use efficiencies of 4.3, 8.8 and 1.7 kg mm^{-1} ha^{-1}, respectively. *Sesbania* fallow increased the soil-water storage in the soil profile and drainage below the maximum crop-root zone compared with the conventionally tilled non-fertiliser maize. Besides improving the grain yields of maize in rotation, *Sesbania* fallows have the potential to recharge the subsoil water through increased subsurface drainage.

Application of agro-forestry technologies therefore result in a number of benefits. They can ameliorate the physical and biological properties of the soil. The organic matter contributed by the biomass improves the activities of the soil microorganisms. The soil will be less compact, have a better porosity and enhanced rain-water infiltration capacity. Also, since the soils are enriched with organic matter, they are more capable of retaining water than the degraded soils under continuous cultivation.

Fruit trees

It is generally accepted that indigenous fruit trees have always played an important role among rural communities in Africa. More than 50 species growing in the wild are used for food and income by the people (Campbell, 1997). Due to the mounting food insecurity and recurring droughts in the southern Africa region, these fruit trees have regained importance. With climate change they will even play a bigger role.

In Malawi and Zambia, as much as 80% of the 323 rural households surveyed in 2001 reported having faced severe food shortages during the months of November and January (Akinnifesi *et al*., 2002). About 50 and 26 % of these households in Malawi and Zambia, respectively, indicated that they resorted to fruit trees during the famine period.

Most of the fruit trees are threatened by anthropogenic pressure and adverse climatic conditions. The ICRAF southern Africa, together with partners, has been working on a fruit tree domesticating strategy. From a survey on the important fruit trees in the region, it was identified that *Uapaca kirkiana*, *Parinari curatellifolia* and *Strychnos cocculoides* were the major important fruit tree species. The studies on propagation and management of the fruit trees were then carried out with special focus on the traits of height, years to fruiting, fruit size, taste and pulp content (Akinnifesi *et al.,* 2002). Normally most of these IFTs would require up to 10 years before fruiting. However, following grafting they could start producing fruits between 2-4 years.

Further studies on clonal selection are being done to improve on taste, size and fruit load.

Value addition work through processing, packaging and marketing has also been conducted with school children and women in Malawi, Zimbabwe and Zambia. Products made include juices, jams, wine, yoghurt and sweets. With collaboration of the Commercial Products Africa Wild (CPWild) the school children and communities have been helped in fostering product quality improvement, assurance and certification. In Zimbabwe, further collaboration with Safire and Tulimara Speciality Products Ltd has been critical in addressing issues of packaging to meet city market standards.

Domestication of IFTs can provide farmers with an alternative or additional source of income, thus strengthening the socio-economic resilience of rural populations. In general, trees have a much higher drought tolerance compared with annual crops because of their strong root system that can track water and nutrients much better into the soil. In addition, tree products, such as timber, fodder, resins and fruits tend to be of higher value than maize or other grains and can provide a useful fall back in the case of crop failure.

Woodlots

Woodlots in rotation with crops are seen as a viable method by which smallholder farmers can be self-sufficient in fuel-wood production. Studies were carried out by ICRAF Tanzania to establish water dynamics in woodlots planted in rotation with crops in a five (5) year cycle. Five tree species—*Acacia crassicarpa*, *A. julifera*, *A. leptocarpa*, *Leucaena pallida* and *Senna siamea*—were compared with natural fallow and continuous maize (Nyadzi, 2004). Intercropping of maize between trees was possible for the first two years of tree establishment without sacrificing maize yield. There was no evidence that the trees were over-exploiting the water reserves after three years. Trees depleted relatively more water than continuous maize and natural fallow, but were able to store more water after rains. Trees retrieved leached inorganic nitrogen and made better use of it than natural fallow and continuous maize.

Wood production at the end of the five-year growing period ranged from 30 to 90 Mg ha^{-1}, whilst carbon sequestered in the above-ground biomass during the same period ranged between 13 to 30 Mg ha^{-1}.Maize yields were higher after growing trees than after natural fallow and continuous maize when no fertilizers were applied. The increase in crop yields after woodlots was attributed in part to higher soil inorganic N. These studies showed that medium-term rotational woodlots have the potential to meet the domestic and industrial wood needs and at the same time reduce deforestation in southern Africa.

Fodder trees

In most of southern Africa, livestock production is an integral part of the farming system because of their input into the cropping system. Livestock provide draught power, manure, milk and meat besides other socio-cultural roles. The productivity of the livestock is constrained by limited availability of fodder particularly during the dry season (Chakeredza *et al.,* 2007). In addition, given the rapid increase in human population in the region, smallholder farmers are encroaching onto farmland which hitherto had been reserved for rangeland livestock production creating a serious conflict. ICRAF-SA has been promoting the use of fodder trees as a source of fodder for cattle particularly in the dry season. The foliage from the fodder trees are high in nitrogen content averaging 3.71 % (23.2 % CP) and can be used to supplement low quality forages available in the dry season for ruminant livestock feeding. The major species being promoted in southern Africa include: *Leucaena pallida*, *L. diversifolia, L. esculenta*, *Acacia angustissima*, *Calliandra calothyrsus*, *Sesbania sesban* (under waterlogged conditions) and *Gliricidia sepium*. To minimise competition with crop farming the fodder trees are grown in the following niche areas: (i) scattered trees in the croplands, (ii) below upper-story tree species along boundary lines, (iii) as hedges around the farm compound and along pathways, (iv) along terrace edges on sloping land, (v) along permanent contour bunds, (vi) intercropped with grasses, and (vii) in home gardens.

With the high occurrence of drought in the region, growing and the use of fodder trees as a source of livestock feed can substantially mitigate the severity of weight losses and prevent livestock deaths when rangeland grazing is limited. On the other hand, a significant number of smallholder dairy farmers in southern Africa have integrated the growing of the fodder trees as a nitrogenous source which they incorporate into the concentrate fraction of the dairy meal. This has led to significant savings on the feed bill, boosting the economics of smallholder dairy production.

Carbon sequestration

The rapid rate of deforestation in southern Africa has significant impact on below ground carbon (C) stocks. Sileshi *et al.* (2007) noted that conversion of woodland to agricultural land depletes terrestrial C stocks by drastically reducing the vegetation C and soil organic carbon (SOC) pools. Introducing agro-forestry species has the potential to increase soil organic matter and store significant amounts of C in wood biomass. For example, Kaonga (2005) studied carbon dynamics in agro-forestry systems in eastern Zambia. He found that coppicing fallows of *G. sepium*, *Senna siamea*, *Acacia* and *Leucaena* spp. store more C than the short duration fallows of *Tephrosia, Sesbania* and *Cajanus cajan.* Makumba (2003) also observed that the gliricidia-maize intercropping practiced in Malawi recycle substantial amounts of above ground C stocks to the soil via the organic materials. In the work of Kaonga (2005), net organic C intakes of improved fallows were found to range between 1.4-4.3 t ha^{-1} yr^{-1} and that of woodlots ranged between 3.5-8.0 t ha^{-1} yr^{-1}. These results were comparable to those of planted and natural sub-humid ecosystems.

Agro-forestry has been found to have two primary mitigative effects on carbon dioxide emissions. The first direct effect is C-storage in trees and soils through accumulation in live tree biomass, wood products, soil organic matter and through protection of existing forests. Secondly, agro-forestry has potential to offset greenhouse gas emissions through energy and material substitution and reduction of fertiliser carbon footprint. Additionally agro-forestry can enhance C sequestration by decreasing pressure on natural forests which are a terrestrial C sink.

It is estimated that the total carbon emission from global deforestation which is estimated at 17 million ha yr^{-1}, is currently 1600 Tg. Assuming that one hectare of agroforestry could save 5 ha from deforestation and that agroforestry systems could be established on up to 2 million ha annually, a significant portion of carbon emissions caused by deforestation could be reduced.

Adoption of Agro-forestry technologies in southern Africa and role in mitigating climate change

To leverage the benefits of agro-forestry to reach many farmers, ICRAF southern Africa has been using a number of approaches. These approaches are also known as PRONGs and defined as follows: (i) Prong 1. Direct training of farmer trainers and local change agents, (ii) Prong 2. Training of partner staff (Government and Non-Governmental Organisations), (iii) Prong 3. Facilitation of farmer exchange visits, (iv) Prong 4. Support to national extension initiatives on sustainable farming, (v) Prong 5. Training of partner staff/farmer trainers by established trained local partners or consultants, (vi) Prong 6. Support to networking, (vii) Prong 7. Establishment and/or strengthening of school community links, and (viii) Prong 8. Sensitising policy makers about the benefits of agro-forestry

In a preliminary study on the effectiveness and efficiency of prongs (Mulila-Mitti, unpublished and undated), ICRAF southern Africa has ranked the top three in order as Prongs 1 > > 2 > 4. The approaches ensure institutionalization of the concept within the national extension systems, educational systems and partner organizations.

Ajayi *et al*. (2007) discusses the adoption of renewable soil fertility replenishment technologies in the southern African region with special focus on agro-forestry. The authors note that the adoption of renewable soil fertility replenishment technologies (RSFR) depend on several factors that can broadly be grouped into: technology specific (e.g., soil type, management regime), household specific (e.g., farmer perceptions, resource endowment, household size), policy and institutions context within which RSFR is disseminated (inputs and outputs prices, land tenure and property rights and geo-spatial (e.g., performance of species across different biophysical conditions, location of village). They further recommend that adoption of RSFR technologies can be enhanced by among others, targeting them to their biophysical and social niches, facilitating appropriate policy and institutional contexts for dissemination and targeted incentive systems that encourage farmers to take cognisance of natural resource implications when making agricultural production decisions.

Up till 2007, the work of ICRAF-Southern Africa had been conducted through the project: "Agro-forestry for sustainable rural development in the Zambezi basin". In the 2007 end of project report prepared for Canadian International Development Agency (CIDA), it is noted that through the provision of timely germplasm and extension materials, building local capacity, increasing awareness of agro-forestry and through policy sensitisation, the project had reached 625,000 smallholder farmers in SADC who have been testing, adopting and using proven agro-forestry technological options. This figure had surpassed the original project target of 400,000 smallholder farmers. It should be noted that the project only covered Tanzania, Malawi, Zambia, Zimbabwe and Mozambique. Efforts are currently underway to also conduct the work in South Africa, Namibia, Botswana and Angola.

Kandji *et al.* (2006) noted that the potential of agroforestry systems as a biophysical and economic buffer against climate variability and food/income risks is well recognised. However, little was known on the possible impacts of higher temperatures, increased atmospheric carbon dioxide and shift in rainfall pattern on the agroforestry tree species on the one hand, and on the other hand, the interactions with food crops. In a drier or warmer climate tree-crop competition for water could intensify. The trade-offs between this type of effects and positive impacts such as microclimate effects and soil protection need to be quantified. Information on pests and diseases in agro-forestry currently also limited. Understanding how climate change will alter the susceptibility of trees to pests and diseases and the effects this will have on their interactions with crops should constitute future studies to be conducted by ICRAF-SA.

Conclusions

The negative impacts of climate change on the livelihoods of smallholder farmers in southern Africa are clear. Climate models are predicting even more unreliable rainfall episodes in the region which would lead to poor crop yields. Governments in the region are strategizing on how to mitigate on the severity of the impact of climate change through largely improving the use of irrigation and the growing drought resistant crops. Agro-forestry has the potential to contribute to buffer farmers against these climate uncertainties and to date over 600,000 smallholder farmers are benefiting from agro-forestry in the region. To apply agro-forestry more widely in the region there is a need to overcome inhibiting socio-economic and institutional barriers. There is also a need to find mechanisms to reward agro-forestry practitioners for environmental services including carbon sequestration, water quality and biodiversity conservation. This could lead to even greater adoption of the technology in the region and beyond.

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8. Forest Dependency and Its Implication for Climate Change Adaptation: A Case Study from Kasane Forest Reserve, Botswana.

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Abstract

Forests play key roles in supporting national economic activities and providing livelihood portfolios for many in Africa. They provide valuable ecosystem services like climate regulation, hazard protection, water conservation, and also affordable goods like fuel wood, foods and nutritional supplements, and medicinal products. Dependency of local communities on forest resources has been identified as a major obstacle in implementing forest protection programmes. This study estimated forest dependency and identified factors influencing dependency for households living around Kasane Forest Reserve (KFR). Data collected from 237 households were analyzed using logistic regression model. Logistic regression suggests that forest dependency is positively and significantly associated with family size. However asset rich households were less dependent on forest resources. Thus, policy makers need to consider the needs and economic options with the above components as an alternative strategy for forest protection for climate change mitigation so as to create a win-win relationship between conservation and local rural development options

Key words: Botswana, forest reserves, dependency, Kasane Forest Reserve, Logistic regression, climate change.

Introduction

Climate change is a global problem that affects all people. The consequences of frequent and extreme weather events, rising sea levels and other climatic changes that damage and degrade these resources cannot be underestimated. However, communities in developing countries are likely to suffer most from the negative impacts of climate change because their lives and livelihoods depend directly upon the fragile natural resources around them (Jarraud, 2003). Although communities are dependent on climate sensitive sectors to meet their basic needs, the communities have limited technological and financial capacity to anticipate and respond to the direct and indirect effects of climate change. Therefore, communities must rely on their ability to adapt to constantly changing and challenging conditions.

Both human activities and natural processes induce climate change. Human activities deplete the ozone layer through the emission of greenhouse gases and reduction of carbon sinks. The combined effect is global warming and consequently, climate change. To reduce human induced climate change requires a multitude of actors to carry out a combination of interventions that include: (i) reducing dependence on fossil fuels, (ii) using available fuels more efficiently, (iii) using more climate-friendly sources of energy, (iii) improving the efficiency of energy technologies, (iv) substituting ozone-depleting substances; and (v) conserving carbon sinks.

The mention of the need to act on global climate change to poor communities might receive stares of incomprehension. Yet, collectively, communities can be the most important participants in protecting the global environment. If the link between protecting the global environment and generating local benefits is made clear and tangible, then communities can be actively engaged to cope with the challenges of climate change. The United Nations Framework Convention on Climate Change (UNFCCC) recognizes that the concerted efforts of nations are essential to slow climate change. While an estimated 1.6 billion people in developing countries do not have access to electricity, do not enjoy modern energy services and do not emit large amounts of greenhouse gases (in stark contrast to communities in industrialized nations), their energy and development needs still need to be met. Therefore, with technical and financial support, poor communities can play an important role in finding adequate responses to climate change and development challenges.

Several studies (Falconer and Arnold 1989, Cavendish 2000, Gunatalike 1998, Bahuguna 2000, Masozera and Alavalapati 2004) have indicated that forests/protected areas are an important source of livelihood for people around them. Forests commonly contribute to nutritional and other basic needs; are a vital source of inputs to agricultural systems; help households control exposure to risk; and are a source of income. Therefore, forest dependency which involves forest based activities and extraction of non-timber forest products is important for subsistence and commercial purposes in developing countries. Since there is no widely accepted economic theory of forest dependency at the present moment, the notion of sustainable conservation for forest protection is supported by this case study which was conducted in Kasane Forest Reserve in Botswana.

The management of forest reserves for the sustainable supply of forest products and provision of environmental benefits is a key aspect of Botswana's forest management practice. The northern part of the country is characterized by open woodland of indigenous hardwoods such as *Baikiaea plurijuga* (Mukusi) and *Pterocarpus angolensis* (Mukwa). The Chobe Forest Inventory and Management Plan estimated that there are 419 800 hectares of forest reserves in the Chobe district containing invaluable timber resources such as *B. plurijuga, Guibourtia coleosperma and P. angolensis*. The majority of these hardwoods are located in the Forest Reserves.

Derivation of products from forest resources such as *B. plurijuga* and *P. angolensis* continues to be under great pressure due to human activities; in particular wood which is a major contributor of fuel energy used in the country. Some of the other major human activities that contribute to the depletion of the forest resources are land use for settlement and infrastructure development, arable and pastoral agriculture, cutting of live wood resources for building poles and fencing material for kraal and homes. These factors together with frequent adverse climatic conditions, bush fires as well as increasing populations of both domesticated and wild animals contribute significantly towards the denudation of forest resources

Background information

Study area

The Chobe District is one of the smallest districts in Botswana and has an international setting. It is located in the extreme northern part of country where Botswana shares boundaries with, Namibia, Zambia and Zimbabwe. The district has a total land area of 22 559 km^2 of which 17 831 km^2 is the total land area of the Chobe National Park and the six forest reserves (Chobe District Development Committee (CDDC), 1997). The District lies within the lines of longitude 24°E and 26°E, and the lines of latitude 17°S and 19°S.

The forest vegetation and associated fauna is part of the Zambezian biogeographical region. In Botswana, Chobe is the only district where the rainfall is just adequate to support more or less closed canopy forest vegetation (NFS, 1992). The *B. plurijuga* forests represent the southernmost extension of the natural range of this species, which is geographically restricted from southern Angola eastwards through southern Zambia to western central parts of Zimbabwe. This vegetation type has a wide distribution throughout sub-Saharan Africa and contains a large number of deciduous tree species, all of which are more or less adapted to periodic fires, low and erratic rainfall.

The study area, the Kasane Forest Reserve (KFR; Total land area 1 360 km^2) is one of the six gazetted forest reserves in Botswana (Forest Act, Chapter 38:04, 1968) all of which are located within the Chobe District. The forest reserves were originally established to protect valuable timber-sized trees from logging operations under Concession agreements (NFS, 1992; Anton, 1997). However, due to the dwindling supply of commercially exploitable timber trees, the logging operations were suspended in 1988 (NFS, 1992).

The KFR is located at the extreme northern corner of the country, adjacent to the Zimbabwe international border and very close to Chobe River, which is also an international boundary between Botswana and Namibia. The reserve is bounded to the north by the Kasane town and Kazungula village, Zimbabwe to the east and Chobe National park to the west (Forest Protection and Development Project, 1996). The total annual rainfall for the district is 500–600 mm, which is the highest in the country.

Potential threats

Although all forest reserves are equally important from an ecological point of view, the KFR will always be most affected by any development plans. This is because of its proximity to the town of Kasane, and the villages of Lesoma and Kazungula. In addition, the forest reserve has a well-developed road network and therefore experiences a lot of human pressure in the form of tourism, private investors, expansion of villages and government installations. The number of threats to the future existence of the KFR is increasing. Apart from the biological threats of the forest such as fire and elephant damage (Department of Forestry and Crop Production, DCP and F, 1996; Nduwayezu *et al.,* 2004), large areas of the forest (about 3060 hectares) have already been de-gazetted for residential purposes of the Kasane town and the expansion of the Kasane airport in 2002.

Land encroachment poses an even greater threat to wildlife conservation because the KFR acts as a buffer zone for the Chobe National Park, which is already under immense pressure from the large elephant population. Discussions with the Departments of Forestry and Tourism in Kasane (B. Losika, Pers. Comm, July 2004.) revealed that a lot of pressure is exerted on the Regional Forestry Office in Kasane by different hotels and enterprises who want to conduct mobile tourist safaris and similar activities in the forest reserve. The over-crowding by tourists in the Chobe National Park seems to be the main reason for justifying their interest in opening up the forest reserves for conducting tourism operations.

Study villages, their historical and socio-economic context

For the purposes of this study, three (3) communities of Kasane, Kazungula and Lesoma that surround the KFR are considered. According to the 2001 census records of Botswana, the population of this area is approximately 10 247, more than half of the total (18 258) for the Chobe District population. This area has one of the highest population growth rate of 4.03% in the country compared to the national average of 2.38% (CSO, 2001). According to the Central Statistics Office (2001) Kasane Township in 1991-2001 recorded the highest population growth rate (6.46) percent in the country.

The village of Kazungula was established by the Wenela Agency in 1935 to recruit workers for the mines in South Africa. The Wenela Agency also started a forest logging industry for the Chobe forests. The establishment of the clinic and school around 1945 and 1949 brought about rapid expansion of the settlement and crop cultivation. The KFR was established in 1968 on the northern edge of the settlement (Anton, 1997). In 1969, Wenela closed its office in Kazungula and many people who originated from Zambia returned to their home country. The start of the liberation war in neighboring Rhodesia (now Zimbabwe) with its frequent cross-border incursions, forced some people to move to nearby Kasane.

The Lesoma village is completely surrounded by protected areas, which include the Matetsi Safari Area on the Zimbabwean side and the Kasane forest reserve in Botswana. The first recorded settlement was in the 1860s around a semi-perennial spring on the valley floor around which cultivation has continued to the present-day. The bulk of the village is located within the KFR following the movement of people away from the international border due to cross-border incursions in the mid and late 1970s at the height of the liberation war in neighboring Rhodesia. In 2000, the Forestry department negotiated a land swap with villagers and the District Authorities. This re-aligned the KFR boundary further away from the Lesoma village. The population of Lesoma has grown from 234 in 1991 to 454 in 2001(CSO, 2001).

On the other hand, Kasane is not a traditional village, but was established around Government Offices of the District Commissioner, District Police Officer and the Forest Officer in the 1950s (Anton, 1997). Kasane (and to a lesser extent Kazungula) is made up of people of varied ethnic and social groups. Many inhabitants have migrated on a permanent or temporary basis from the other villages in the District into Kasane. In addition to a number of government officers, a number of expatriates are staying in the district, mostly involved in the tourism sector and arable farming. There is improved infrastructure and good housing, although there is shortage of land as the area is surrounded by the Chobe National Park, the Chobe River and the forest reserves.

The implication of this migration is that unemployment in Kasane continues to rise (CDDP5, 1997).

Methods

Kasane, Kazungula and Lesoma, the three villages surrounding KFR where the study was conducted, have a total of 2657 households (CSO, 2001). From this, a sample size of 237 households was selected which was approximately about 10% of population size. Within the selected villages, a list of the households was acquired from the District Council Offices from which a simple random sample was applied to select households. Sampling was done by writing down names of residents' households on pieces of paper and these were put in a box from which names of the household owners were drawn at random based on the location of the wards. The choices of respondents based on the location of the wards were done in order to ensure equal chances of selecting different land uses around the PA (arable farmers, livestock farmers, tourist operators) and location-specific factors (e.g., distance to the Protected Areas). Where the household owners were unavailable, it was not possible to go back to visit the household in the evening for fear of wild animals; therefore in such cases, where the head of the chosen household was not available at home, the adjacent or a nearby household was selected.

Survey design

The survey instrument contained both close and open ended questions. The questions asked were related to resource use, perceptions, the demographic characteristics and socio economic data. The data on household characteristics included (gender, age, household size, residency and education [ability to read and write, non-formal, primary, secondary and tertiary level] and occupational data).

Model specification

Household's dependence on KFR was calculated as the ratio of annual income earned from forests to the total annual income earned from wealth and other sources (agriculture, off-farm employment, and the KFR). The procedures that were followed to derive income from each source are explained below.

For this analysis, the forest dependents are defined as the households having a positive income from forest related activities (see explanation below for calculating percentage of forest income below). Forest dependency is classified based on the relative forest income rather than the absolute forest income. Relative income is used because it is difficult to say what level of absolute income determines the forest dependency. Relative dependency is classified as the percentage of full income contributed by forest products while absolute dependency is classified as quantities of forest products collected (Pattanayak *et al.,* 2003). The model used to estimate forest dependency is as follows:

$$\text{Ln}\,(P_i /1- P_i)= \beta_0+ \beta_1 X_1 + \ldots + \beta_k X_{ki}. \quad (1)$$

Where:

i denotes the i-th observation in the sample

p is the probability of dependency on forest resources

β_0 is the intercept term
$\beta_1 \ldots \beta_k$ are the coefficients associated with each explanatory variable $X_1 \ldots X_k$.

The impact of age, gender, education, household size (HHsize), total wealth assets (Weassets), and number of years living in the area (Resident) on forest dependency is estimated.

Household income was computed for each household based on the information provided by them. The computation of household income was carried out as follows:

- Household Annual Income = ∑ (Forest Income + Agriculture Income +Return to Wealth + Wage Income)
- Forest Income = ∑ (Fuel wood annual income + wild fruits income+ poles income + Thatching grass income)
- Agriculture Income = ∑ (maize income + sorghum income + millet income + Beans income)
- Wealth (Assets) = ∑ (Livestock Assets + Household Assets)
- Livestock Assets = ∑ (Cattle income + Goats income + Sheep income + Donkeys income + Pigs income + Chicken income)
- Household Asset = ∑ (Radio price + TV price + Bicycle price + Tractor price + Donkey cart price + Car price + Cell phone price + Fridge price + Bed price)

Forest income: Information about collection and sale of forest products was obtained from households. In addition, a list of all non-timer forest products (NTFP) was prepared with key informants and the Forestry Staff and Document reviews as a checklist to remind respondents about product they might forget. Products such as thatching grass, fuel wood can be traded commercially to generate cash while subsistence products such as medicinal plants, wild fruits and fuel wood are used for household consumption. Income from commercial products was calculated by multiplying the quantities with market prices. Income on subsistence products was computed based on surrogate prices.

Agriculture Income: Agriculture includes cultivation of crops for purposes of both household consumption and selling. Information on crop yields was gathered from individual households through the questionnaire survey. Prices of crops were obtained from the local market or through the Botswana Agricultural Marketing Board (BAMB) which sets prices for the sale of crops in the country.

Wage Income: Information on salaried jobs and business was collected from individual members. This also includes other sources of income such as remittances, and pensions for age old people. This information was provided by the respondent.

Other household assets: The annual rate of return on capital (livestock, tractor, and car) was computed as a product of the price and the interest rate. The interest rate used for this study was 10% which was determined after discussion with relevant departments in Botswana. In certain cases such as prices for cattle, goats and other livestock, the surrogate market price was used depending on the age of the animal. Other assets such as small items such as radios, bicycle, and television, the respondent was asked how much he will be willing to sell that item at the current market.

Since there was no basis for assigning the forest dependency index from Botswana Government sources, the dependency index in this particular study was divided at the median (Sah and Heinen, 2001). Although there are a few cases in the 40% range and beyond, the majority of cases are clustered at the lower end of the scale, with most of them falling below 8%. These high values for only a few cases have a significant effect on the mean but little or no effect on the median, making the median a better indication of central tendency in this example (Mertler and Vannata, 2005).

It is assumed that households whose forest income represents greater or equal to a value greater than 8% of the total income are dependent on the forest, while households whose forest income represents less than 8% of the total income are less dependent. Thus, the variable is assigned a value of zero (0) if the household forest dependency is < 0.08 and a value of 1 if the household dependency index is ≥ 0.08. The binary nature of the dependent variables suggests that a logit model is appropriate (Gujarati 1995). The categorical explanatory variables, education are recoded as 0 representing "those with above primary education level as educated (1) and those below primary education level as (0). Gender was also recoded as 1 and 0 respectively, male (1) and female (0). Before presenting the results of estimation, a brief description of each explanatory variable and expected theoretical relationship to forest dependency is provided below.

Age

People of all ages can be forest dependent, however young people may be more dependent on forest products than elderly people may. The reason for this is that the young people may have multiple uses of the forests and more so forest products collection is labor intensive. On the other hand, the elderly people may not take a risk of going into the forest to undertake forest activities particularly that the elderly people may not have the strength to carry out forest related activities (Kohlin and Parks 2001). It is therefore hypothesized that forest dependency is inversely related to age.

Education

In general, education opens up better employment opportunities for people, thus diverting them from agricultural and other subsistence activities (Hedges and Enters 2000). The higher social status of the educated, government or private sector employees may also restrict their involvement in forest dependent activities since they can afford the modern type of lifestyle e.g. using gas stoves or electricity for cooking. Therefore, it is hypothesized that forest dependency is inversely related to the education level of members of the family.

Gender

Both the males and females can be dependent on the forest. However, women and men collect and use different forest products, for different uses (Campbell *et al.,* 1993). The collection of firewood and medicinal plants are joint activities, while the collection of thatching grass and wild fruits are exclusive chores for women. Cutting building poles is exclusively a man's activity. Because collection of forest products is prohibited and in some cases there is a danger of wild animals in these areas, men are more likely to take the risk of going into the forest when compared with women. It is therefore hypothesized that male-headed households are more likely to be more dependent on forest resources than female-headed households are.

Household size

Families with more labor tend to extract more forest resources (Gunatilake, 1998; Hedges and Enters, 2000; Masozera and Alavalapati, 2005) because they are able to mobilize part of their families to undertake forest dependent activities while maintaining a labor supply for other village–based activities. Furthermore, larger families have higher subsistence needs, and that may be another reason to depend more on forest resources. Therefore, it is assumed that larger households are directly related to forest dependency.

Wealth assets

Wealth assets are calculated in this study as the sum of physical and livestock assets. In rural Africa, livestock acquisition remains a key form of wealth accumulation (Dercon, 1998 cited by Fisher 2004). In the Chobe District, scarcity of land and the Tsetse fly disease limit cattle rearing. Livestock is relatively liquid asset that can be sold in response to price fluctuations, or for consumption or to provide financial capital to start a business or to pay for the acquisition of household assets. It is hypothesized that people who have more livestock and other household assets are inversely related to forest dependency, because livestock rearing is one of the stable sources of income for the households (Fisher, 2004). Therefore, it is expected that asset-rich households are less likely to exert pressure on forest resources.

Duration of residence

Long-term residents are likely to be more knowledgeable about the ecological structure, composition and seasonal patterns of the forests and hence collect more forest products (Pattanayak *et al.,* 2003). It is therefore expected that length of residency is directly related to forest dependency.

Results and discussion

Forest resource utilization

As in most other parts of the country and in this region in particular, firewood is still one of the most important source of household energy (Table 8.1). However, only 138 (58.2%) of the households reported ever going into the forest reserve. Most households are virtually asset-poor and the distributions of key assets are unequal. The use of building poles and thatching grass has declined significantly in the study area as compared to a decade ago (Anton 1997). This is shown by a shift towards corrugated iron roofing by households in the study area (personal observation).

Although there is widespread selling of handicrafts to tourists by both men and women at the market place (personal observation), all of these products were bought from traders from the neighboring countries of Zimbabwe and Zambia and others from the neighboring remote areas of the Chobe Enclave. Residents attribute this to the scarcity of local material for making handicrafts in the Kasane Forest Reserve (KFR). Residents also felt that the availability of fruits was declining due to an increased population in recent years of elephants and baboons which either damage the trees or pick the fruits before they are ripe for human consumption. Thatching grass is becoming more difficult to find due to the lack of annual early burning to promote fresh vigorous growth in the next growth season. According to villagers in the survey, this was due to disagreement between the Forestry Department and the local people on certain management decisions such as the timing of early burning.

Results of the model explaining forest dependency are presented in Table 8.2. The likelihood ratio test shows that the regression model is significant with Chi-Square statistics of 37.58. This result indicates that the explanatory variables in the model are significantly related to forest dependency. The results show that the model predictions are correct 72.60% of the time indicating that the explanatory variables can be used to specify the dependent variable, in discrete terms (1,0), with a moderate degree of accuracy. Coefficients of Household size (HHsize**)** and Wealth assets (Weassets**)** are statistically significant at 5% significance level. Other explanatory variables, Gender, Age, education and Residency, the coefficients are generally small and insignificant too. The positive association between household size and forest income indicated that larger households tended to derive more income from forests. The variable Household size

Table 8.1. Frequency distribution of forest resources collected in KFR

Category	Frequency	Percent
Forest Resources		
Fuel wood	128	54.0
Building Poles	2	0.8
Wild Fruits	15	6.3
Thatching Grass	2	0.8
Handicrafts	4	1.7

Table 8.2. Logistic results of forest dependence

Variables	B	S.E.	Wald	Exp(B)
Gender	.064	.330	.037	.938
Age	.016	.014	1.360	1.016
Education	-.268	.478	.315	.765
Resident	.016	.013	1.542	1.016
Household size	.144*	.051	7.946	1.155
Wealth assets	-.00044*	.000	7.613	1.000
Constant	-1.851	.965	3.679	.157
Correct Prediction	72.6%			
LR Test	37.58			

* Coefficients significant at p<0.05

(HHsize) shows a positive relationship with forest dependency. This suggests that large families tend to depend more on forest resources. The effect on the probability of forest products utilization (collection) of increased family size is further pronounced when the household lacks other income generation options such as formal employment. This result concurs with the findings on fuel wood collection reported by Köhlin and Parks (2001). Kgathi *et al.* (2004) also found a positive significant relationship between household size and fuel wood consumption in Mmankgodi, Botswana. Though regression model revealed that fuel wood consumption increased as household size increased, each subsequent increase in household size was associated with a lower increase in fuel wood consumption in proportional terms because large households tend to use fuel wood more efficiently than small households (Kgathi *et al.,* 2004).

The variable Weassets shows a negative relationship with forest dependency which is consistent with the prior expectation. This implies that households with larger wealth assets are less dependent on forest resources. Asset-endowment of the household was included in this analysis in terms of value of household assets and value of livestock held. The only plausible explanation for this result could be that people who have large herds of livestock are unlikely to have time for harvesting forest products as they have to spend most of their time herding their animals. This finding is corroborated by other studies in Africa (Barrettt *et al.* 2001) and elsewhere (Sills *et al.* 2003; Takasaki *et al.,* 2000). However, the use of basic and advanced technology e.g. donkey cart and trucks by well off community members may lead to overexploitation of the forest resources, hence denying those who do not have the new technology access to the forest resources. This could even be more detrimental where regulations and rules governing the resource use in a forest reserve are not enforced.

Potential impacts of climate change on Botswana's forests

There currently is a strong lack of information on the potential impacts of climate change in Botswana. There is still considerable uncertainty on how the local climate of the different agro-ecological zones will be affected by global climate change. Even more uncertainty exists with regards to changes in weather extremes, although there are some first indications that the variability of the climate may increase, in particular in Africa's drylands.

Changes in natural vegetation

Change in rainfall patterns alters the extent of arid, semi-arid and dry sub-humid areas. Savannas, a common dryland vegetation type in Africa especially in Botswana , are likely to be particularly affected by global climate change as their water balance and vegetation are quite sensitive to water balance changes induced by temperature and precipitation changes. The areas of Grassland in Botswana may decline to be, replaced either with Thorn Scrub Savannah or Seasonal and Dry Forest. Desert areas may expand northwestwards into the Chobe District from the southwest (Kgalagadi District).

Impacts on rangeland activities

The impacts of climate change will be mostly incremental, accelerating existing processes of environmental change with respect to rangelands. Climate change is expected to accelerate bush encroachment and a switch from cattle to smallstock since the latter are better adapted to marginal conditions. These ecological changes may have the following impacts on human activities: a reduction in overall development potential because of reduced useful biomass and a loss of biodiversity; changes in the suitability, profitability and attractiveness of different sectoral activities; lower overall incomes; and reduced livelihood security coupled with increased income inequalities

Wildland fire

The most important way in which climate change affects Botswana's forest may be through fire. Climate and fuel interactions may increase fire risks because drier and longer summers which is a phenomenon in Botswana, clearly increases fire hazards and risks. Long term moisture stress makes trees more susceptible to pathogens such bark beetles, which exacerbates stress and can, push trees past survival thresholds, causing forest die-offs and increased fuel loadings from dead trees. Forest fires are likely to become more prevalent in the future because summer is expected to get hotter and drier.

Conclusions and recommendations

The understanding of the dependency of households on the KFR is critical in the development of management strategies. Reducing the human pressure on biologically rich hot spots and conserving valuable genetic resources has been and still is a fundamental policy concern in many countries. In the face of rapidly growing human populations in and around the bio-diverse regions of the tropical forests, sustainable use of forest products, both timber and non-timber forests products is not easy. This research analysis reveals that forest resources in the protected forest area are an important component of the households' activities. About 54% of the sampled households reported collecting fuel wood from this area for home consumption and/or income generation.

The result from the logistic regression reveals that rich in assets households (mainly livestock owners) are less forest dependent. This suggests that the financial attractiveness of the collection of forest product is more pronounced on less diversified farmers than on more diversified farmers, perhaps as the means of portfolio diversification. This implies that asset-rich households are less likely to exert pressure on the KFR. Furthermore, the study reveals that educated and employed households, although not statistically significantly different, are less dependent on forest resources. If the government provides employment opportunities through alternative livelihood options such as tourism, the dependence on the KFR might be reduced. The present study also indicates that forest dependency is positively and significantly associated with family size. This study is supported by the findings on energy uses in Botswana by Kabaija (2003) who reported that small-sized households (1 to 3) persons predominantly used gas for cooking while larger-sized households used wood, which is the "cheaper" energy source. This difference may be attributed to the fact that more energy is used in cooking than lighting. Hence larger-sized households cook more food leading to more energy for cooking, and hence are forced to use the cheaper energy source.

Controlling household/family size through the provision of favorable policy incentives could help reduce the residents' dependency and extraction pressure on the trees being conserved in the protected areas. Particular attention here needs to be given to households with large numbers of adult family members who are unemployed and need alternative means for income generation. This means that the welfare of elderly people and resource conservation may be promoted through diversifying income sources such as increasing monthly pension, which is currently very low, about US$ 18 per month.

However, one positive aspect in relation to the use of energy sources in Botswana is that the use of fuel wood as an energy source has been on a consistent decline since the 1981 population census. The general pattern therefore appears to be one of an increase in the uptake of conventional energy sources and a decrease in the uptake of traditional energy sources, particularly fuel wood (Kabaija 2003). These are welcome developments particularly in view of the fears of unsustainable use of wood resources for energy uses. Botswana can rely on the following alternatives/opportunities in order to reduce pressure on the already dwindling forest resources:

Firstly, Botswana has an abundance of one source of energy whose use is environmentally friendly, and that is solar energy. Therefore, the potential for solar energy can be exploited, particularly in rural communities that are not catered for by the national electricity power grid. In addition, the National Development Plan 9 (NDP 9) Energy sector policies and strategies that could have a positive impact on the improvement of this sector include:

Continuation of the collective rural electrification scheme (which allows for only 5% down payment in rural areas and a repayment period of 15 years). This payment method makes it easier for poor households to connect electricity to their households.

- Improvement in safety aspects and distribution of illumination paraffin and gas- especially in rural areas where there are no service stations.
- Support of the introduction and use of other fuels (e.g. cow dung, coal) and other appliances such as coal stoves.
- Ensuring the sustainable use of fuel wood by promoting fuel efficient stoves.

Efforts to conserve the KFR through restricted access, might lead to the impoverishment of the already poor households which are reliant on collecting forests products, especially fuel wood. However, forest protection could in fact benefit the poor if it leads to a rise in prices of harvesting permits for those that collect firewood for commercial purposes. More importantly, policies that focus on securing forest access by the poor and maintaining them in the KFR may actually perpetuate poverty and overexploitation of the resource, if other development options are overlooked (Anglesen and Wunder, 2003). A more effective pro-poor and pro-forest conservation strategy may be one that assists the poor in moving out of the KFR and into more gainful employment. Towards this end, public investment creating employment opportunities and promoting self-employment (e.g. educational spending, food-for work interventions and micro-lending programs),are highly recommended, Forest-based approaches, such as market development for under-exploited products like wood crafts and palm crafts from *Hyphaene pertasiana* for making baskets, may be more effective. A very high potential exists in this area, which is the hub of the tourism sector in Botswana. Such programs can increase local incentives to sustainably manage forest resources. Nevertheless, careful implementation is necessary, because the rise in non-timer forest products (NTFP) may encourage over-harvesting of resources and decrease incentive for local residents to participate in forest management (Jumbe and Angelesen, 2004). This needs special attention in areas such as Kasane and Kazungula that are highly populated urban centers with a strong market economy from the tourism industry coupled with the scarcity of some of these NTFPs in the Forest Reserve.

Programs that encourage tree planting outside natural forests may foster other approaches in reducing dependency on forest resources and attaining forest conservation. One possibility is community-company partnerships: these have proven useful for conserving natural forests and improving rural welfare in many areas (Scherr *et al.,* 2002). Companies provide necessary materials, low interest loans, and technical assistance for establishing small woodlots on farm or customary land. In return, companies have the sole rights of buying the mature trees. Botswana government through the Department of Forestry and Range Resources has initiated such projects in other parts of the country. However, the feasibility of such programs in the land-scarce and problem-animal Chobe District requires further investigation. Perhaps the most feasible intervention is the promotion of tree planting around homes, which has been quite successful elsewhere in Botswana due to the tree protection afforded by the family members.

Lastly, the government should consider and act upon the creation of alternative employment and income sources. The use of the forest reserves in Chobe including the KFR is more appropriate because Safari companies have already expressed interest in using the forest reserve to conduct game drives and other tourist activities (Ross 2001). The communities could benefit by sharing a percentage of lease revenues, or take a more proactive role in tourism ventures and forest management. The demand for daytime tourism activities from the numerous tourists staying in Kasane Township gives the KFR potential as a tourist center. Activities may include day game-drives, walking safaris, naturalistic or scientific groups, bush dinners, bird watching and community based utilization of NTFPs such as crafts in tourist markets. The activities also seem to be particularly appropriate for the KFR due to its lower wildlife concentration when compared to the Chobe National Park. This would permit safer walking, bird watching and other botanical activities (Ross 2001). The lower wildlife densities of the KFR which could be a disadvantage could also be an advantage by diversifying the activities available for tourists in the Chobe district. The diversification of activities also allows for the potential generation of jobs, an increase of local skills and maintenance of traditional cultures.

In summary, to enhance greater cooperation from local people and achieve sustainable conservation and utilization of the forest reserve, greater stakeholder participation is recommended in the design of any management plan. A sustainable action plan should use the forest to pay its own management costs and allow surrounding communities to benefit; hence, they can see the forest reserve as worthy of the protection. Caution should be taken to avoid marginalizing other members who use the reserve for their basic needs. This will require critical consideration and integration of conservation of the resource with peasant household development in the area.

Climate change is one, but only one, of a large number of constraints which will govern environmental policy formation in SADC over the years to come. Its role should not be exaggerated, nor should it be ignored. The interpretation of the findings of this study in relation to adaptation strategies and environmental policy formation, however, must fully recognize the larger matrix of environmental and developmental imperatives which will influence environmental policy creation in SADC in the years to come. For example, climate change is likely to add only further incremental stress to ecosystems already under severe pressure because of population growth (throughout the region), increasing subsistence needs (throughout the region), endemic droughts (most of the region), unequal land distribution and a very limited coping ability (particularly in communal rangelands).

The way forward

More research is required to understand how African agro-ecosystems will respond to climate change, how livelihoods will be affected, and how adaptation could take place. However, clearly, development support cannot wait for the results of such research. Economic development, more sustainable resource management and reductions of high fertility rates will all contribute to both poverty reduction and to increasing the capacity of Africans to cope with climate change. Mainstreaming of subjects related to climate change into the curriculum in Agriculture and Forestry institutions in Botswana should be given priority. Significant enhancements of the scientific capacity within government and university to conduct fundamental and applied research and provide extension services in both impacts and adaptation, and climate modeling are required to move the climate change agenda forward. In addition the needs, of rural communities who must deal with the realities of climate change on a day- to- day basis should play an increasing role in guiding research priorities.

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9. Climate Change Vulnerability and Adaptation Strategies in High and Low Rainfall Areas of Malawi and Tanzania: Case Studies of 16 Villages

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Abstract

In many sub-Saharan African countries including Malawi, smallholder rainfed agriculture underpins most rural livelihoods and national economies. In these countries, declining agricultural productivity has been linked to worsening poverty and increasing food insecurity. Climate change and variability are another major challenge already playing a major role on agricultural productivity. Rural people have therefore developed traditional adaptive strategies to cope with effects of climate change on agricultural productivity. Studies have shown that these coping strategies are mostly short term and have low adaptive capacity. This paper presents initial results of an on-going action research on such adaptive strategies in two villages located in areas with contrasting climatic characteristics in Mulanje and Chikwawa Districts in Southern Malawi and Mzimba and Karonga in Northern Malawi and Central Tanzania and Southern Highlands of Tanzania. The study used the participatory rural appraisal approach to assess local farmers' perceptions on climate change, their vulnerability and adaptation strategies. The results indicate that most agricultural livelihood activities are linked to rainfall levels and frequencies which have been varying. The farmers have developed some adaptive strategies such as crop diversification, conservation agriculture and irrigation farming but lack capacity for implementation. Further, livestock farming seems to be a favourable alternative but access to seed funding is limited in most households especially in the high rainfall sites. Timely access to vital and simple information on climate change and variability is also a major challenge. There is therefore a clear need for the improvement of sharing of information related to climate change and variability, promotion and support of the coping and adaptive strategies already which can be sustainable in the long run.

Key words: Climate change and variability, Adaptation, Rural Livelihoods, Vulnerability, Agricultural productivity.

Introduction

Climate change and uncertainties derived from annual climatic variability remains a major challenge to rural livelihoods in Africa. In many sub-Saharan African countries including Malawi and Tanzania, smallholder agriculture underpins most rural livelihoods and national economies. Over 70 percent of population depends on agriculture for their livelihood. In these

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countries, declining agricultural productivity has been linked to worsening poverty and increasing food insecurity. Agriculture is mostly subsistence in nature and predominantly rain-fed (Katz and Brown, 1992; Bazzaz and Sombroek, 1996, WRI 1996; Wamukonya and Rukato 2001). Agriculture in these countries is therefore highly vulnerable to changes in climate variability, seasonal shifts, and precipitation patterns. Climate variability is likely to increase under global warming (Environmental Affairs Department 2002a, 2002, National Statistics Office 2005). Climate change with expected long-term changes in rainfall patterns and shifting temperature zones are expected to have significant negative effects on agriculture, food and water security and economic growth in all African countries; and increased frequency and intensity of droughts and floods is expected to negatively affect agricultural production and food security (DFID, 2004; Kinuthia, 1997, IPCC, 2001a, 2001b, Nhemachena and Hassan, 2007). In Tanzania and Malawi the adverse effects of climate change may particularly be felt by poor communities who are dominantly located in rural areas because of their low adaptive capacity associated with limited financial resources, poor infrastructure, low level of education, dependence on natural resources and lesser access to technology. The low level of human development, poverty, and high dependence on agriculture and natural resources in Tanzania and Malawi increases their potential vulnerability to future climate change.

Given the impacts associated with climate change and variability, strengthening the agricultural innovation system is among the key areas of intervention as communities face challenges in adapting to climate change. A serious effort on identifying, understanding and enhancing sustainable adaptation is therefore crucial. Adaptation to climate change is the adjustment of a natural or human system to moderate the impacts of climate change, to take advantages of new opportunities or to cope with the consequences (Klein, 2001; Adger *et al.,* 2003). Improved adaptation particularly in areas where climate variability is large holds the key to sustainable livelihoods. A better understanding of farmer perceptions regarding long-term climatic changes, current adaptation measures and their determinants is therefore important to inform policy for future successful adaptation of the agricultural sector.

In Tanzania and Malawi, a key challenge for decision makers is to understand the context and strategies of farmers and other stakeholders in agriculture for adapting to climate change, including increasingly variable climatic conditions. Diverse farming environments and complexities associated with the context of peoples' livelihoods varying over time and space suggest a need for localised innovation to enhance and sustain productivity. There is therefore a need to foster processes for two-way communication and *engagement amongst these stakeholders and for supporting their information and other needs in order* to strengthen farmers' and other stakeholders' capacities to adapt.

The Institute of Resource Assessment (IRA) of the University of Dar es Salaam, Tanzania is hosting a research program under Climate Change Adaptations in Africa (CCAA) in collaboration with the Natural Resource Institute (NRI) of the University of Greenwich in the UK and the Natural Resources and Environment Centre (NAREC) of the University of Malawi. This is an IDRC funded four years program established recently to address climate change adaptation issues in Africa particularly on capacity building to African scientists and other stakeholders. The title of the project is "**Strengthening Local Agricultural Innovative Systems in Less Favoured (semi-arid) and More favoured (high rainfall) Areas of Tanzania and**

Malawi to adapt to the Challenges and Opportunities arising from Climate Change and Variability". In this project, action research is targeting farming communities in two contrasting sites (low and high rainfall areas) per country together with local, district, national, regional and international stakeholders and identifies/accesses information to be shared and used to develop agricultural innovation systems better able to adapt to climate change and variability (CC and V). A combination of a sustainable livelihoods framework and innovations systems thinking provide a conceptual frame and a learning alliance approach will guide our action research. The project builds on: Trans-disciplinary partnerships and initiatives in agriculture and natural resources; Tanzania's and Malawi's NAPAs (National Adaptation Programmes of Action), which prioritize agriculture; Farmers' livelihood strategies in relation to climate change; and other agricultural stakeholders' (public and private) strategies. The process includes distinguishing agro-ecologically and socio-economically more and less favoured areas and direct and indirect benefits to the vulnerable at local scale through improving participating individuals, organizations and systems ability to utilize knowledge more effectively, efficiently and sustainably in addressing local, national and regional priorities that will contribute to adapting to climate change. The process will systematically identify and share lessons with key decision makers for further capacity strengthening to enhance innovation and adapt to climate change in ways that benefit the most vulnerable.

The Innovation Systems concept, although originating from policy debate in more industrialized countries in the 1970s and 1980s, still provides useful insights into strengthening agricultural innovation capacity in developing countries. An Innovation System (IS) may be defined as a 'network of organizations, enterprises and individuals focused on bringing new products, new processes and new forms of organization into economic use, together with the institutions and policies that affect their behaviour and performance' (Agricultural and Rural Development - ARD World Bank 2006). It will benefit our project because the emphasis of the approach is not only on professional scientists but the totality and interaction of actors involved in innovation. The IS concept moves beyond the creation of knowledge and encompasses factors affecting demand for and use of knowledge in novel and useful ways (Arnold and Bell, 2001).

Objectives of the study

One of the first activities for the project was a situational analysis of the study sites. A study was therefore conducted from October 2007 to January 2008, to analyze the situation in high and low favoured areas of Malawi and Tanzania on farmer's knowledge perceptions regarding changes in climate, vulnerability, adaptation options and their determinants as well as barriers to adaptation, within a broader livelihoods context. The results were used to identify potential areas for action research that would strengthen local farmers adaptive capacity to climate change and variability. This paper briefly presents the findings of the survey.

Specifically, the objectives of the study were to:

1. Understand farmer perceptions of climate change and variability in a wider setting of changing vulnerability context, policies, institutions and processes.
2. Understand impact of climate change and variability on livelihood activities (particularly agricultural/ natural resource management activities)

3. Identify the characteristics of adaptation capacity/ vulnerability and what are the key factors influencing them [Adaptive capacity/ vulnerability – potential]
4. Explore how community and individual livelihood strategies are influenced by climate change and variability [Adaptive strategies – future]

Methodology

Description of the study sites

The survey was conducted in all the project's study villages, eight in Tanzania and eight in Malawi. In each country four villages were selected from semi-arid districts (Chikwawa and Karonga for Malawi and Bahi, Singida and Kongwa for Tanzania) and high rainfall districts (Mulanje and Mzimba for Malawi and Mufindi, Mbeya, Kyela and Njombe for Tanzania). The project sites in Tanzania and Malawi per agro ecological zone are indicated in Tables 9.1 and 9.2.

Development of research tools and use

A range of different methods were adopted to address the objectives of the survey. The following methods were developed and used for data collection.

- Focus group discussion (women and men separately with wide age range)
- Key informants interviews
- Individual interviews
- Direct observations

A checklist for focus group discussions covering each objective was developed and translated into Chichewa and Tumbuka widely spoken languages in the southern study sites (Mulanje and Chikwawa) and northern region sites (Mzimba and Karonga) respectively for Malawi and into Swahili for Tanzanian sites.

Sampling and data collection

The survey used purposively selected 8 to 15 participants for both male and female focus group discussions (FGDs) taking into consideration age of the individuals. Female and male FGDs were conducted separately because weather and climate knowledge is learned and identified by farmers within a cultural context and their knowledge base follows a specific process. Local knowledge provides a framework to explain the relationships between particular climatic events and farming activities. Men and women usually have different kinds of knowledge and use it for different purposes (Rengalakshmi, 2007). A number of 8 to 15 key informants were also selected. These included the village headman, elderly people, and village development committee members holding agriculturally related posts. Six individuals were interviewed as case studies. These were selected representing the three wealth groupings (poor, middle and rich) categorized based on the socio economic criteria provided by the key informants. Age differences and gender balance were also considered in the selection. Fieldwork was carried out from October to November 2007. The main unit of analysis was the **household.** This was defined as those living within the same compound, and who worked or contributed food or income to the unit. There are inherent difficulties and limitations in such a definition, especially when used across countries and cultures, and not all households regard themselves in the same way.

Table 9.1. Brief characteristics of project sites in Tanzania

		Agro-ecological/ biophysical factors	
		High Potential Area	Less Favoured Area
Socio-economic	High	Nyombo (Njombe district) Kapugi (Rungwe district)	Sanjaranda(Manyoni district) Chibelela (Bahi District)
	Low	Mwitikilwa (Mufindi) Mpunguti Makwale (Kyela)	Maluga (Singida district) Laikala (Kongwa district)
Rainfall regimes and patterns in the zone		Unimodal rainfall in Njombe from November to May, ranging from 1000 to 2000mm/year. In Rungwe and Kyela is also unimodal starting from October to May ranging from 1500 to 2300mm/year and between 800 to 2300 mm/year in Kyela.	Unimodal rainfall in Njombe from November to May, ranging from 1000 to 2000mm/year. In Rungwe and Kyela is also unimodal starting from October to May ranging from 1500 to 2300mm/year and between
Temperature regimes in the zone		Temperature often below 15ºC in Njombe and Mufindi and around 16ºC in Rungwe	Temperature often above 16ºC in most areas but ranges between 16ºC and 23ºC, representing a typical semi-arid condition. The hottest period lasting from October to April.
Major soils in the zone		Predominantly fertile volcanic soils in Rugwe, vertisols/fluvisols in Kyela, Ferrasols/Luvisols/Fluvisols in Njombe and Mufindi	Predominantly dry and poor sand soils, typical Ferrasols in Maluga and Kongwa, dominant vertisols in Chibelela, Ferrasols/Arenosols in Iramba
Hydrology of the zone		Endowed with a number of permanent large and small rivers e.g. Ruaha, Songwe, Ruhuji, a number of permanent wetlands, a couple of crater lakes in Mbeya	Have few seasonal rivers e.g. Bubu in Bahi and Ndurumo in Iramba, large seasonal wetland in Bahi and Iramba, few rift valley lakes in Singida as well as few man made dams
Dominant vegetation in the zone		Dominant vegetation is Miombo woodlands in Rungwe and Kyela. In Njombe and Mufindi, humid forest remnants characterises the area. Extensive grassland are also found	The dominant type of vegetation in Dodoma is woodlands associated with grass land and scattered bush and shrubs. In Singida, dry miombo woodlands dominate as well as thickets in Itigi, manyoni district.

Table 9.2. Brief characteristics of project sites in Malawi

		Agro-ecological/ biophysical factors	
		High Potential Area	**Less Favoured Area**
Socio-economic	High	Mtambalika (Mulanje district) Kacholola Ndhlovu (Mzimba district)	Mphampha (Chikwawa district) Muyeleka (Karonga District)
	Low	Nessa (Mulanje) Samuel Mphepo (Mzimba)	Mpasu (Chikwawa District) Mwayuweyu (Karonga district)
Rainfall regimes and patterns in the zone		In Mulanje rainfall is unimodal starting from November to April. Amounts depend on altitude in relation to the mountain which causes higher rainfall in the windward side than the leeward. From June to August the district experiences occasional winter rains and fog. Annual rainfall varies from 600mm to 650mm in the western parts (leeward side) of the district and over 3000 mm in other parts. Unimodal rainfall in Mzimba from November to April-May, depending on topography, position and other factors such as El Nino, La Nina ranges from 3000 to 6000mm/year.	Unimodal variable and unreliable rainfall in Chikwawa from November/December to April/May, ranging from 170 to 967.6mm/year. In Karonga rainfall is also unimodal starting from November to April/May ranging from 500 to 2000mm/year
Temperature regimes in the zone		Mean annual temperature is 22.4 ºC for Mulanje and go slightly below 0ºC in winter In Mzimba the annual mean temperature varies from 15.5 ºC to 19.8 ºC	Temperature are generally high ranging from 27.6 ºC to 37.6 ºC and a monthly mean of 20 ºC In Karonga temperature ranges from 20 ºC to 35 ºC
Major soils in the zone		Mulanje district has four major soil types: clay-loam, sandy clay-loamy, sandy-loam and clay soils Mzimba is covered mainly with medium to light textured but moderately fertile soils with eutric – fersialic soil characteristics. The soils have moderate to good drainage.	Upland soils in Chikwawa are predominantly cambrisols or luvisols (moderately deep, medium textured, well drained and yellowish brown. Lowlands soils are varied; luvisols, fluvisols, vertisols and gleyols/ambisols with widespread deficiencies of phosphorus and nitrogen

		Karonga soils vary from area to area: weathered ferralitic soils/latosols, lithosols and undifferentiated lathosols, alluvial soils, often calcimorphic soils, lithosols and gleys
	Agro-ecological/ biophysical factors	
	High Potential Area	**Less Favoured Area**
Hydrology of the zone	In Mzimba, there are valleys along South Rukuru, Kasitu and Dwangwa rivers (Kabuwa area). South Rukuru is the biggest and longest river in the district and region. It meanders from the South to North of the district through Henga Valley in Rumphi. Lake Kazuni is situated on this river near Vwaza marsh in the North The land in Mulanje is undulating and has several rivers and streams that flow down the mountain. The major rivers are Ruo, Likhubula, Lichenya and Thuchila. Likhubula, Lichenya and Thuchila are tributaries to Ruo which joins Shire River down South.	Chikwawa-Thyolo Escarpment forms the major source of over 8 rivers such as Likhubula. Other rivers in the district are Mwanza, Phwadzi, Nkombezi, Lalanje and Shire is the major outlet In Karonga: Sengwe. Kyungu, Lufira, North Rukuru, Nyungwe, Wevwe, Hara, Hangalawe and Chitimba rivers drain the lakeshore plain zones. Most of the other rivers are seasonal
Dominant vegetation in the zone	A distinction in natural vegetation is observed in 5 altitude bands. These include Miombo forests, woodland dominated by Brachystegia species, evergreen forests, Secondary scrub and rolling grassland and Mulanje Cedar (National Tree of Malawi) Mzimba is largely covered with natural evergreen forests and woodland forests predominantly with semi – evergreen woodlands of *Brachystegia julbernardia* and erythrophloeum. There are also thickets of combretum, commiphora and euphorbia interspersed with brachystegia woodlands and also extreme artificial plantation forests of pinus and eucalyptus species around Viphya/Chikangawa grassland with forest remnants,	The dominant vegetation in Chikwawa is acacia thicket clump savanna (terrestrial type) and marsh grassland and reed vegetation (aquatic type). Karonga is mostly described as open canopy woodland of hills and scarps, where thin and stony soils occur dominated by brachystegia species

Some data from key informant interviews was used to validate data collected through the FGDs and individual interviews. Some of the data collected through these qualitative methods was validated scientifically through quantitative climate data from the weather stations close to the study sites. This included years of very heavy and little rainfall or droughts. The communities were also visited again after three months of initial data collection and invited for a stakeholder consultation workshop three months later after the second visit to validate the data collected in the first visit to the village.

Data analysis

The survey was qualitative in nature. Therefore, all data collected was thematically analyzed. Thus data was categorized into major emerging themes. Tables were used to present summaries of data obtained from the key informants and the FGDs. The discussion also included the data captured in the individual interviews.

Results and discussion

Farmers perception to climate change and variability

Farmers described their climate in relation to temperature, rainfall and winds. They noted changes in temperatures and variability in rainfall. Annual precipitation is variable both in quantity and distribution during the rainy season. Rainfall variability and occurrence of extreme events are more pronounced in terms of onset and cessation of the rain season, number of rain days, rainfall intensity, and the magnitude of drought and flood events. For example, in Mulanje sites, before 2003 the rainy season covered October to April. Currently, the villages experience delayed on set of rains. Currently, the rains start from November to March signifying a shortened growing season. Whereas the rainfall amounts in high rainfall areas both in Malawi and Tanzania remain high, they have reduced in semi-arid. In the semi-arid areas, the rains are heavy in few days followed by prolonged dry spells. The sites are frequented with floods. The aged reported that these changes started around 1970s but extreme events such as floods and droughts are more frequent than a decade ago where it would take about 10 years before an occurrence. Currently, these have become almost yearly occurrences mostly in less favoured/semi-arid sites. Table 9.3 provides farmers perceptions for all the study sites.

Table 9.3: Farmers perception to climate change and variability

Tanzania		Malawi	
Low potential area	**High potential area**	**Low potential area**	**High potential area**
-Climate (temperature, rainfall, wind, whirl wind) -Temperature increasing -Rainfall decreasing more unpredictable - Late onset and early cessation of rainfall	-Climate (temperature, rainfall, dew, wind, lightning) -High temperature starts early, cool period increased -Late onset of rains and unpredictable -Dew decreasing	Climate (temperature, rainfall, wind, whirl wind) -Temperature increasing -Rainfall decreasing and more unpredictable -Late onset and early cessation of rainfall (shortened rain season) -Unpredictable floods -prolonged dry spells	-Climate (sunshine, rainfall, dew, coldness) -High temperature starts early -Cool period extended -Still high amounts of rains but poorly distributed -Late onset and early cessation of rainfall (shortened rain season), unpredictable -Increased frequency of floods and droughts

A comparison with scientific data show similar trends (Figures 9.1 to 9.9) below depict temperature trends and rainfall patterns for selected sites in both Malawi and Tanzania. In general temperature variation (maximum and minimum) in the study areas (semi-arid and humid southern highlands) has indicated an increase in both agro ecological regions. Specific details are discussed below:

- The maximum temperature in Dodoma on the average has been slightly below the mean for quite a long time 1964- 1998 when the maximum temperature immediately started to increase continuously to date.
- The maximum temperature for Mbeya station initially rose up from below the mean (1964-1982 and thereafter increased continuously to date.
- Maximum temperature records in Iringa station went down from 1961 to 1970 and increased again continuously to date.
- The Minimum temperatures in Dodoma initially were below the mean value (1961) of about 16.8 degrees C but continued to increase past the mean value around 1986 and continued to increase to date. The period with the highest rate of temperature increase is 1995 onwards.
- Minimum temperatures in Mbeya steadily decreased below the mean and turned around in 1971 and continued to increase from 1970 to date. The period which showed the highest temperature increase was from 1998 onwards.

- Minimum temperature profile in Iringa indicates that temperatures started from low figures in 1961 and kept on increasing past the mean around 1973 and oscillated down again to reach a low in 1995 when the series increased steadily to date. The period when the increase of temperature was highest was between 1996 to date.
- Mean annual rainfall in Dodoma station in semi-arid area shows that rainfall has been fluctuating from low to high and vice versa. For example rainfall increased from 1933 to 1946 decreased again continuously until 1975 when it reached the bottom and picked again to a high in 1995. Then from 1995 to date overall the rainfall has decreased steadily.

The above pattern is that rainfall in Dodoma has been fluctuating within about a 20 - year cycle and currently we are heading for downward trend for some time. Analysis of other stations in the semi-arid and Southern Highlands is going on and their relationships worked out.

In Malawi, the following has been observed;

- Maximum temperature analysis for Mimosa (nearby weather station for Mulanje Sites) shows a marked positive trend. Warming is very evident from around 1987- this corresponds to global trends. The minimum temperature for Mimosa shows a positive trend. Again, a marked warming from 1987 is evident.
- Mzimba maximum temperature analysis shows a very prominent positive trend. A marked warming can be seen from around 1988 to the end of the data series. This corresponds to global trends. Minimum temperature analysis shows a weak positive trend indicating night/early morning warming over the area.
- The maximum temperature for Ngabu (nearby weather station for Chikwawa sites) shows a declining trend suggesting that the area is becoming cooler. More studies are needed to establish the cooling mechanism. However, the years 1983 and 1992 were hotter than the average (32.3 ^{o}C) and the year 1999 was slightly cooler. The minimum temperature depicts a positive trend. The year 1974 had very low minimum temperature while the year 1992 had very high minimum temperature compared to the mean of 20.40^{o}C
- The maximum temperature for Karonga depicts a steady increase from the 1970s to 2000. A positive trend is obvious which means that the area is getting warmer as time passes. The minimum temperature shows a steady fluctuation about the mean, with a weak positive trend, again signifying night or early morning warming.
- In terms of rainfall, a constant trend is depicted for Mimosa (mean 1609.5). The seasons 1988/89 and 2000/01 had extremely high rainfall while the seasons 1991/92 and 2003/04 had lower rainfall. (Here, it seems extremes in rainfall are of prominent concern).
- The Mzimba rainfall pattern shows a declining trend and regular peaks of very high or very low rainfall. For example, the seasons 1978/79, 1989/90 and 2001/02 were very wet while the season 1996/96 had very little rainfall.
- The rainfall pattern for Ngabu in Chikwawa shows a constant trend or fluctuation about the mean. However, episodes of two little rainfall seem to dominate, for example in 1982/83, 1992/93. The season 2001/02 received excess rainfall.
- The rainfall pattern for Karonga depicts a generally declining trend. The season 1979/80 was extremely wet while the seasons 1994/5 and 1997/98 received too little rainfall.

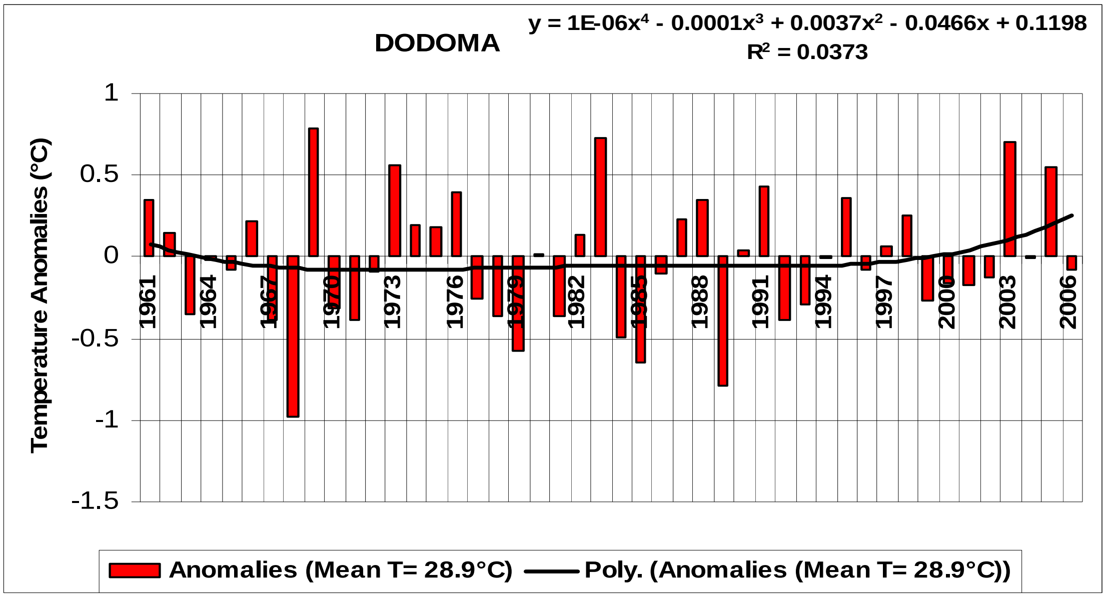

Figure 9.1 Anomalies of Maximum Temperatures in Dodoma 1961-2006

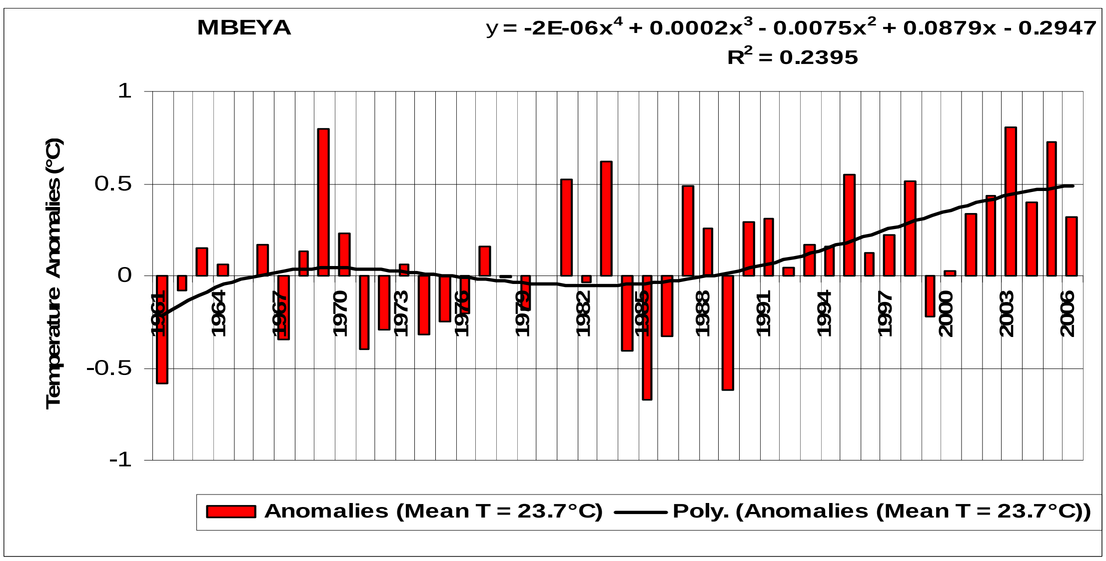

Figure 9.2 Anomalies of Maximum Temperatures in Mbeya 1961-2006

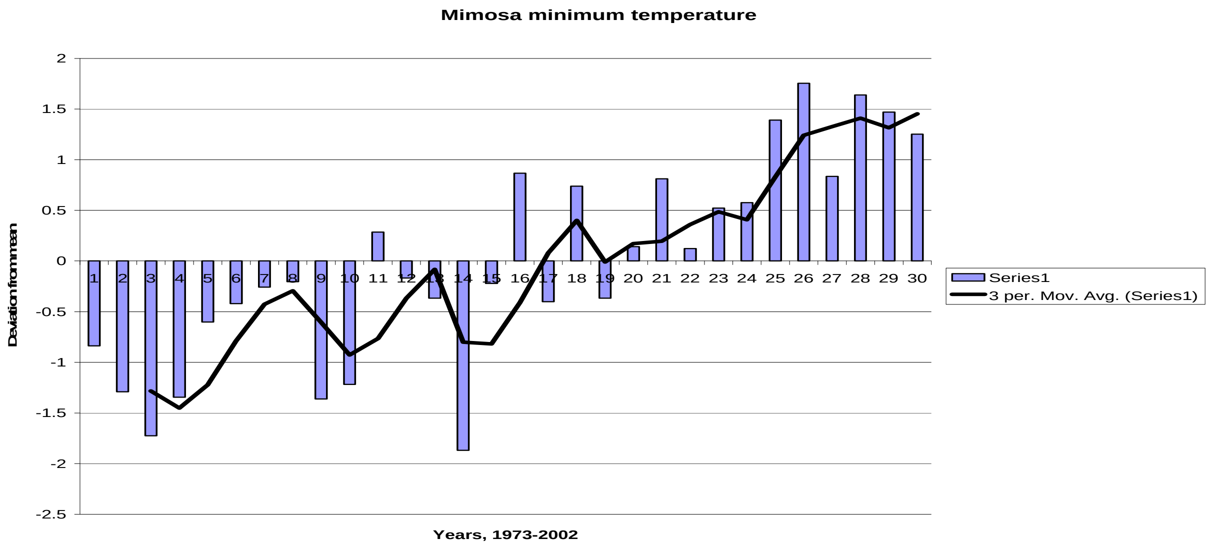

Figure 9.3: Mimosa mean temperatures from 1973 to 2002

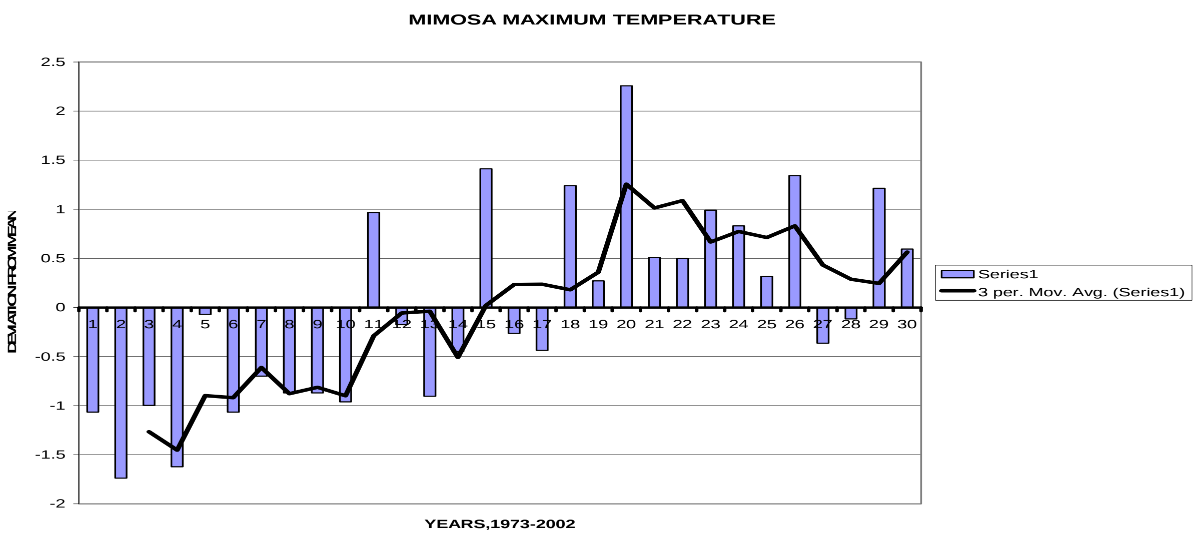

Figure 9.4: Mimosa Maximum temperatures from 1973 to 2002

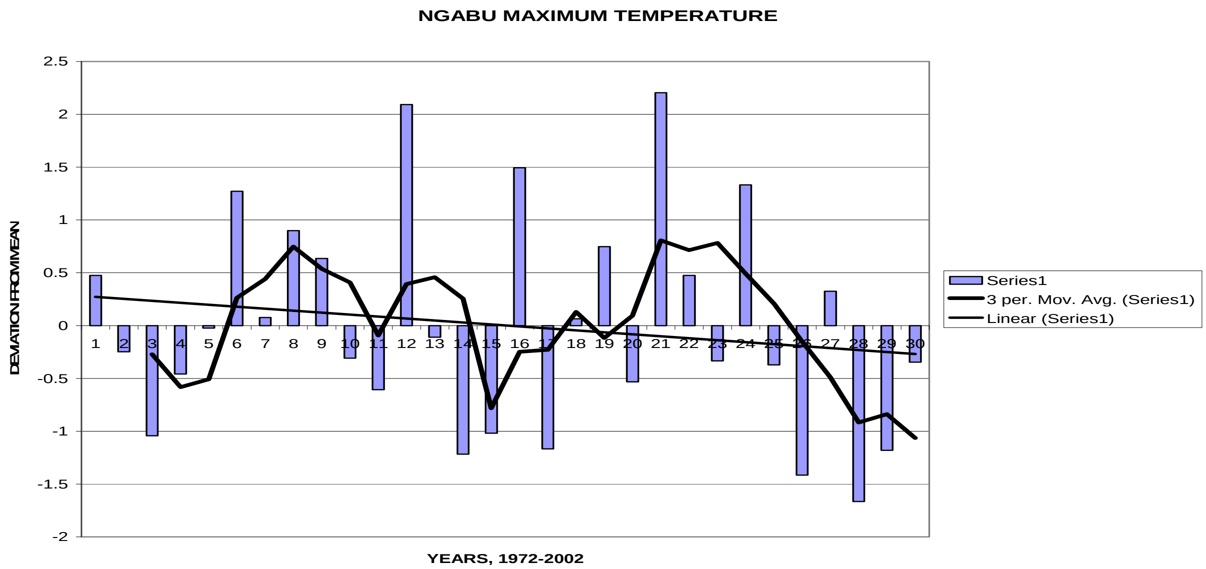

Figure 9.5 : Ngabu Maximum temperatures 1972 to 2002

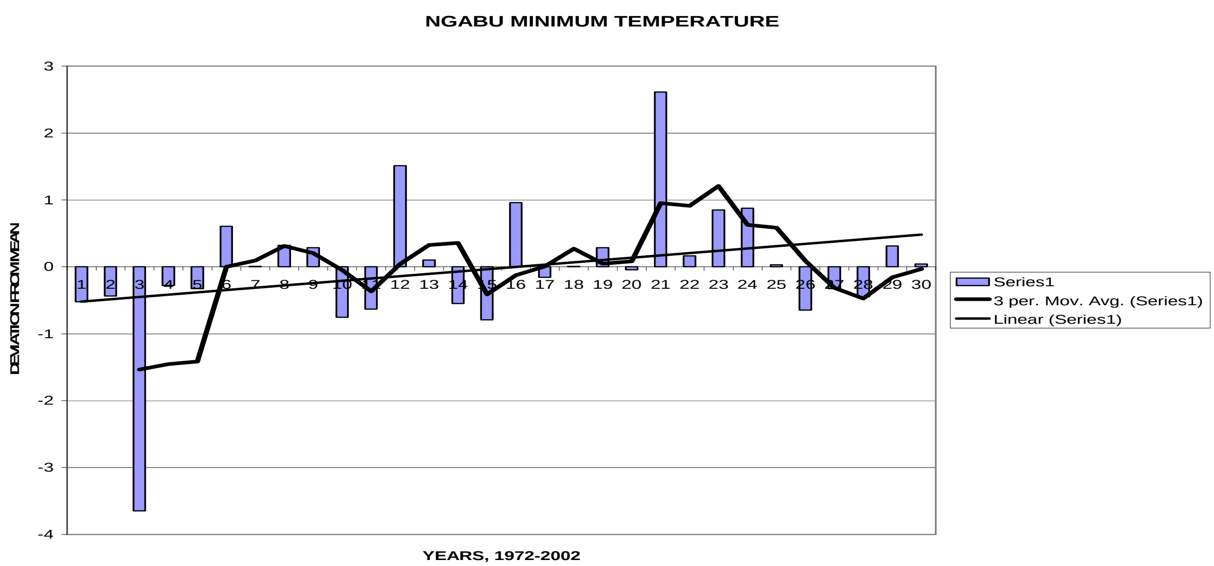

Figure 9.6. Ngabu Minimum temperatures 1972 to 2002

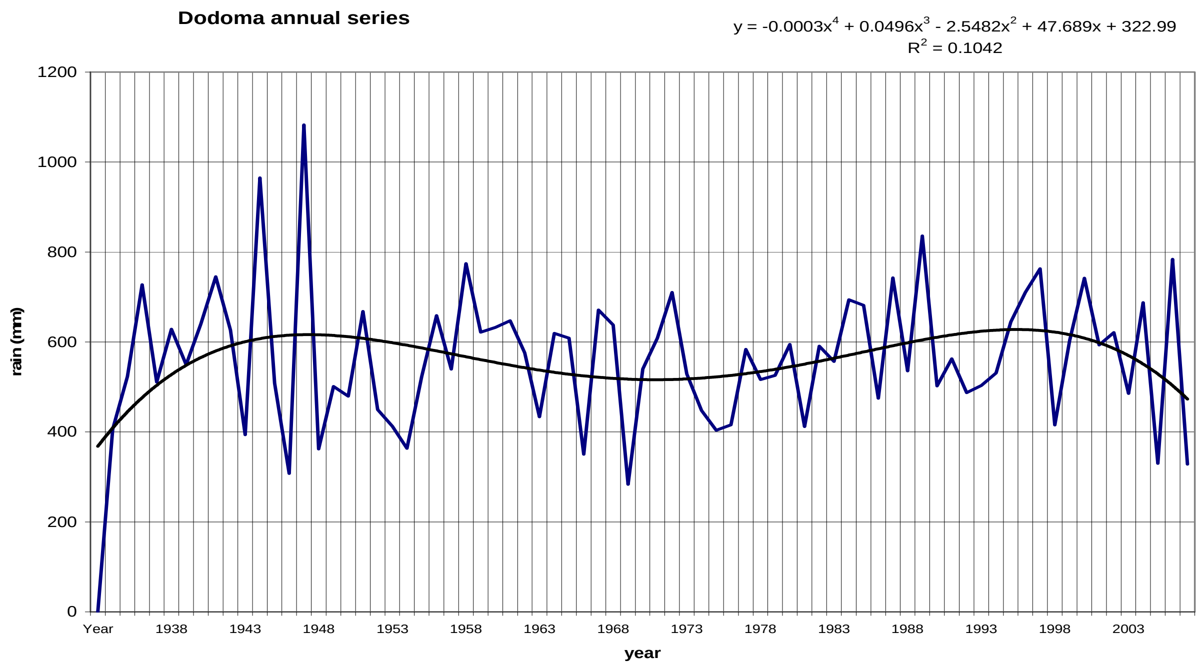

Figure 9.7 : Rainfall anomalies in Dodoma, 1920s to 2005

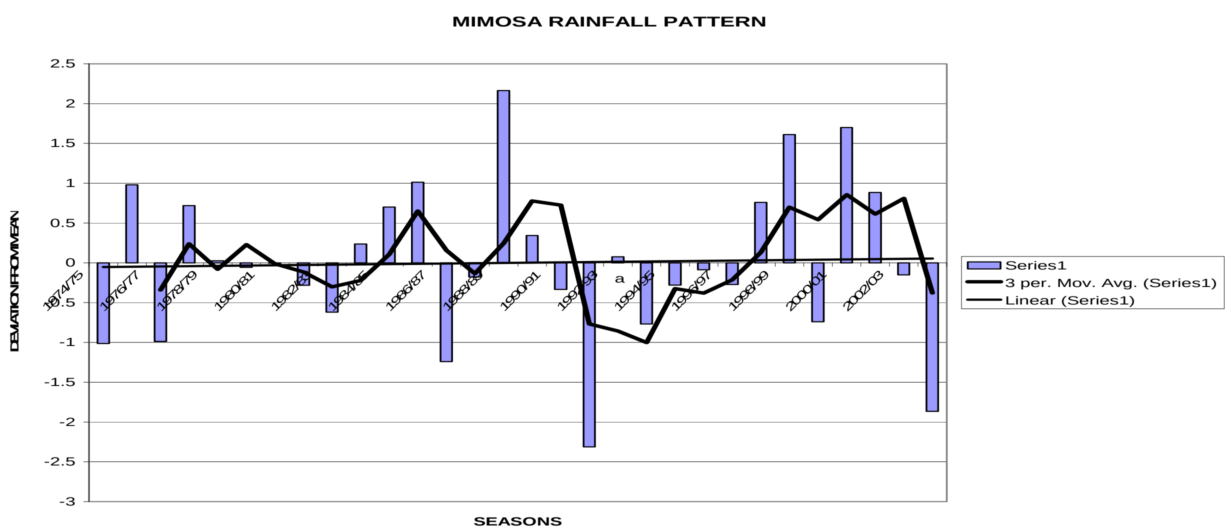

Figure 9.8 : Rainfall anomalies in Mulanje District, 1973 to 2002

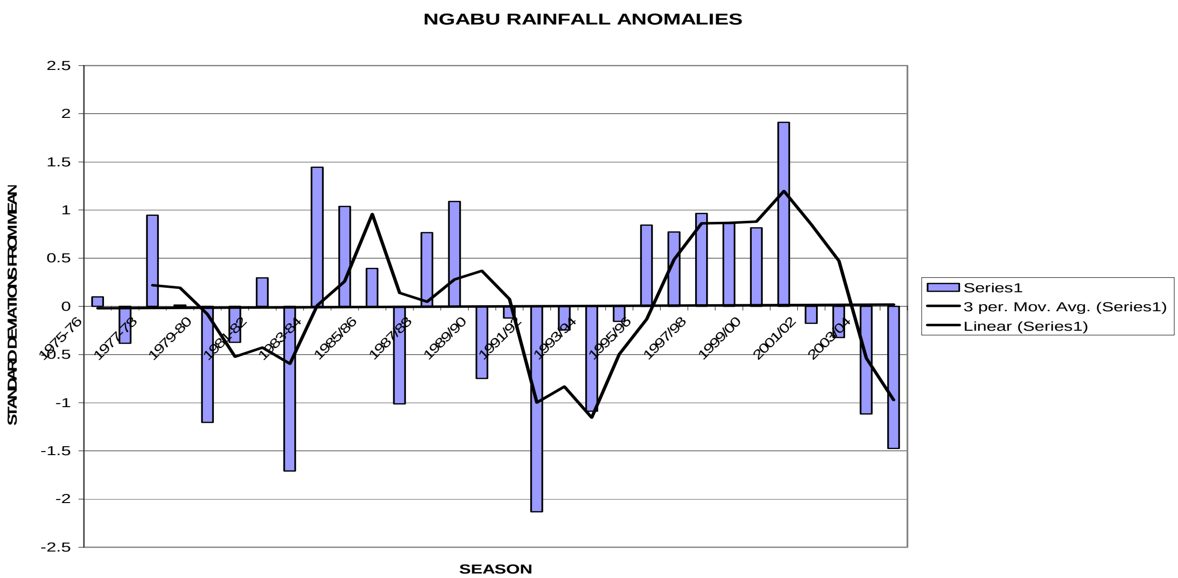

Figure 9.9: Ngabu rainfall anomalies 1975 to 2005

Impacts of climate change and variability

The changes in temperatures and variability have impacted people and natural resources in a number of ways. Table 9.4 outlines some of the impacts. Farmers have abandoned some traditional crops due to declining rainfall in less favoured areas. This has also happened in high rainfall areas. Heavy rains accompanied by landslides and floods have changed the soil structure hence favouring new crops which were not previously grown in the areas. For example, in Nessa Village, Mulanje, Malawi, pineapples which are dominant crop replaced maize after a land slide in 1985 which eroded soils. Occurrences of extreme events also affect people's livelihoods negatively. For example when there are droughts, productivity goes down. Famine and loss of jobs prevail for those working in tea estates in high rainfall areas. These results converge with studies done in Morocco and Algeria where Benbelkacem (1996) established that delayed rains lead to crop failure. The agriculture sector within many countries of sub-tropical southern Africa is vulnerable to changes in the onset of rains and the frequency of dry spells. Both of these attributes have experienced and are experiencing change with consequences for crop production and food security (Karanja *et al*., 2007).

Table 9.4: Impacts of climate change and variability

Tanzania		Malawi	
Low potential area	**High potential area**	**Low potential area**	**High potential area**
-Declining crop yield -Traditional crops abandoned -Poor livestock production -Increasing livestock diseases (ECF)	-Decline soil fertility -Stunted crop growth -Destruction of mature crops in the field and stored ones due to shift of rainfall	-increasing hunger periods -increasing dependency on natural resources-loss of human property due to floods-reduced feed for livestock due to droughts	-Landslides and soil erosion -Crops damaged -Loss of jobs -Animal loss due to floods -Increasing malaria

Vulnerability and coping strategies of the communities to climate change and variability

Vulnerability is typically described to be a function of three overlapping characteristics: *exposure*, *sensitivity*, and *adaptive capacity* (Turner *et al.,* 2003). For example, agricultural vulnerability to the effects of CC could be described in terms of exposure to elevated temperatures; crop yield sensitivity to the elevated temperatures; and the ability of farmers to adapt to the effects of that sensitivity, such as by planting more heat-resistant cultivars or by ceasing to plant their current crop altogether. Although all rural communities are vulnerable, vulnerability in the study sites depends on one's socio-economic status. The poor, women, children and elderly who predominantly relies on farming, have little agricultural land (less than 0.5 acres), limited access to credit, farm input and assets which can be disposed of for cash to buy food supplies when crops fail are the most vulnerable. These have little capacity to cope to impacts associated with rainfall variability.

The poor mostly use unsustainable means to cope to challenges associated with CC and V. The coping strategies include beer brewing, sell of firewood, charcoal (thus contributing to further deforestation in the study sites), begging and sell of casual labour to better off farmers hence giving little attention to their own farms. Although the rains are favourable in the following growing season, productivity may not improve hence poverty prevails. The better off use their savings and sell some of their assets such as livestock to cope.

Adaptation strategies and challenges to adapt to climate change and variability

Studies show that in spite of the low adaptive capacity of Africa, people have developed traditional adaptation strategies to face the great climate inter-annual variability and extreme events. Those communities who have experienced harsh environmental conditions over prolonged periods, have consequently been trying, testing and adopting different types of coping or adaptive strategies to moderate or cope with the impacts of climate change and variability (WRI 1996). Adaptation activities are spatially and temporally more locally based (i.e. district, regional or national) than international issues. This is because different communities in different geographical locations and scales possess different vulnerabilities and adaptive capabilities, and so they tend to be impacted differently, thereby exhibiting different adaptation needs. Hence, adaptation largely consists of uncoordinated action at household, firm and organization levels. This may also involve collective action at the local, national, regional, and international levels and cross-scale interaction where these levels meet (Paavola *et al.,* 2005; Parry *et al.,* 2005). The communities in the study sites have developed a number of adaptive strategies locally or with the help of other institutions working in the areas. Most the strategies are sustainable. Table 9.5 presents some of the adopted strategies. These include adoption of high yielding hybrid varieties, drought resistant and early maturing varieties. Crop diversification incorporating fruit trees and tubers, livelihood diversification including non-farm activities such as basket weaving and pottery. Fish farming is also being promoted including winter and supplemental irrigation utilizing water from the fish ponds and rivers. Livestock production is also being promoted especially in high rainfall areas.

Table 9.5 Adaptive strategies to climate change and variability

Tanzania		**Malawi**	
Low potential area	**High potential area**	**Low potential area**	**High potential area**
Use drought resistant crops (e.g. sunflower) Small scale irrigation of crops Increasing non-farm income generating activities Use of appropriate crop varieties (early maturing) Introduction of new crops	Increasing wetland farming Improved social networks Use of improved seed varieties Use of artificial fertilizers Networking	Increased, cassava cultivation Traditional irrigation of crops in dimba Improve agronomic practices Increasing non-farm income generating activities Migration Change of crops grown Staggered planting	Increased use of -Irrigation farming - crop diversification - fruit Trees and tubers -early maturing hybrid varieties -organic manure Promotion of -afforestation and goats Production -Change of crops Grown Fish farming and irrigation

However, the farming communities meet a number of challenges to implement these strategies. The following are challenges encountered.

1. They lack capacity to implement adaptive strategies such as crop diversification, conservation agriculture and irrigation farming. For example, they have problems to select proper crop varieties and use irrigation water sustainably without compromising the needs of other uses and users downstream.
2. Further, livestock farming seems to be a favourable alternative but access to seed funding is limited in most households especially in the high rainfall sites.
3. Timely access to vital and simple information on climate change and variability is also a major challenge. Onset of rains is unpredictable hence they need timely weather information for proper farming preparations
4. Due to resource limitations such as crop land, accessibility to loans and farm inputs, farmers fail to meet transaction costs necessary to acquire adaptation measures and at times farmers cannot make beneficial use of the available information they might have
5. Poor infrastructure. There are other institutions such as NGOs in agricultural innovative systems who are helping communities to develop better adaptive strategies. However, some sites are poorly located hence sidelined by these interventions
6. Poor access to external markets. The communities have products which can help them cope such as fruits in high rainfall areas and livestock in semi-arid sites however; they have poor access to markets. They sell products to middle men at very low costs.

The current and future adaptive strategies outlined in this section show that farmers are using crop management practices that include use of irrigation, water and soil conservation techniques and varying planting and harvesting dates to ensure that critical, sensitive growth stages do not coincide with very harsh climatic conditions in the season. These strategies can also be used to modify length of the growing season; for instance irrigation and water conservation techniques are an important source of additional water that can be used to lengthen the growing period of different crops (Nhemachena and Hassan 2007). It is also noted that these adaptation measures are not independent strategies but should be used in a complementary way. For instance, the use of irrigation technologies needs to be accompanied by other good crop management practices such as use of efficient irrigation systems, growing crops that require less water and using improved irrigation water use practices. However, the survey did not establish farmers knowledge of this complementarity. Furthermore, although the survey established these adaptation measures in response to changes in climate, it is noted that these actions might be profit-driven rather than responses to changes in climate. However, for the purpose of this study it is assumed that farmers are using these strategies in response to climate change and variability. Similar findings were established in a related study conducted by Nhemachena and Hassan (2007) in South Africa, Zambia and Zimbabwe.

Suggested areas for action research

The communities prioritized a number of activities that they expect the project to assist in implement in collaboration with relevant stakeholders such as meteorological and agricultural departments, NGOs and research institutions. Below are prioritized activities for some specific villages in Malawi

Samuel Mphepo

1. Irrigation Farming
2. Crop and Livestock Diversification (Mushroom)
3. Capacity Building on Climate Change
4. Manure Making
5. Soil and Water Management

Kachotola Ndhlovu

1. Capacity Building on climate change and adaptation
2. Crop diversification and selection
3. Livestock farming
4. Catchment management (river bank protection) - Mzimba

Muyeleka Village

1. Crop Diversification e.g. drought tolerant crops i.e. cassava, early maturing crops
2. awareness meetings on climate change
3. trainings on land resource management
4. By-laws on proper utilization of food and animals which destroy crops

Mwayuweyu Village

1. Afforestaion
2. Training on soil and water conservation techniques including promotion of nitrogen fixing crops
3. Capacity Building on climate change
4. Water harvsting techniques

Conclusion

The communities are aware of the climatic changes and variations that are taking place and have developed adaptive strategies at local level which are mostly sustainable if they are given the necessary support for example in terms of capacity building. The increased uncertainty in climatic phenomenon is a big challenge to communities in planning for the current and future adaptation strategies. We cannot predict the exact impact of climate change but the overall consensus is clear and what is required is efficiency in disaster risk management. With continued rainfall variations and occurrence of extreme events, the project intends to strengthen the capacity of these communities and relevant stakeholders in innovative systems through various strategies or for a that will help to improve access and sharing of information related to climate change and variability, promotion and support of the coping and adaptive strategies already which can be sustainable in the long run.

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10. Vulnerability of Fishes and their Biodiversity to Climate Change in Developing Countries: A Review

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Abstract

Global climate has changed, and is increasing atmospheric temperatures, acidification of oceans, reducing dissolved oxygen, affecting nutrient delivery, decreasing agricultural productivity, increasing food insecurity, promoting economic instability and disrupting the ontogeny and biodiversity of aquatic organisms. Climate change may affect growth, reproduction, distribution, and production of fishes. The fisheries resources of Malawi are already over fished and the impact of climate change could further destabilize the country's already dwindling fish stocks. Fishing reduces age, size and biodiversity of fishes, so the fisheries resources could become more vulnerable to additional stress from climate change. High precipitation raises water levels in lakes and rivers, erodes fertile soils, and destroys spawning sites of some economically-important fish species, but prolonged drought could reduce water levels, kill aquatic organisms, and cause a collapse of the fishing industry. Mitigation strategies against the impact of climate change should call for multi-sectoral collaboration among scientists, technologists, private sector, and government. Institutions could produce human capacity, facilitate research, impart technological knowledge, and engage in outreach activities. The impact of climate change on fisheries could be eased by re-examining fisheries management agenda, strengthening the ecosystem management approach, maintaining an effective ban on alien fish introductions (in Malawi), and protecting the fisheries resources. Reducing fishing mortality could significantly reduce the impact of climate change on fisheries, but this is a fisheries management battle that appears to have already been lost at global level. Nations could be proactive by developing early warning systems, protecting the environment, sensitizing citizens on the impact of climate change, and identifying alternative sources of livelihood whenever aquatic resources are suddenly destroyed. Education and training are important national tools for building adequate and sustainable human capacity. Thermal tolerance studies on fishes could also help to identify suitable fish species for intensive aquaculture in different eco-geographical zones of Africa.

Key words: Fishes, climate change, temperature, biodiversity, Africa

Climate Change Overview

Climate change

Climate change (and the broader term global change that includes climate change) has now almost become a common household term (Lange, Roderfield and Leemans*,* 2008). Global change includes climate variability, land use, water storage and irrigation, human population growth and urbanization, trade and travel, and chemical pollution (Suthers, 2004). Most climatologists believe that global climate change is occurring as a result of greenhouse gas emissions from the combustion of fossil fuels, clearly implicating human activities for global warming. Excess carbon dioxide, methane, and other gases which trap heat are accumulating in the troposphere, the earth's lower atmosphere, because of the scale and type of human economic activity (McMichael, 1997). The causal link of climate change to greenhouse gas emissions is therefore, well established (King, 2004).

The components of climate include: atmospheric temperatures, land and ocean, the extent of sea ice, mountain glaciers, the sea level, distribution of precipitation, and the length of seasons which are changing (Revkin, 2008). Human actions are also changing many of the world's natural environmental systems, including the climate system (McMichael *et al.,* 2008). It is reported that between one-third and one-half of the land surface has been transformed by human action (Vitousek *et al.,* 1997). Analysis has recently shown that no area is unaffected by human influence, and that a large fraction (41%) is strongly affected by multiple drivers (Halpern *et al.,* 2008). Human pressures on the environment are also damaging the world's biophysical and ecological systems (McMichael *et al.,* 2008).

The management and conservation of the world's oceans therefore, require a synthesis of spatial data on the distribution and intensity of human activities and the overlap of their impacts on marine ecosystems (Halpern *et al,* 2008). After building up within the atmosphere, these gases cause unprecedented changes to the earth's climate (Greer, 2008). The changes occur because greenhouse gases act as a blanket, trapping the infrared radiation, and heat the earth further (Helfman, Collete and Facey, 1997). It has been shown that the concentration of carbon dioxide in the atmosphere has increased by nearly 30 percent since the beginning of the Industrial Revolution (Vitousek *et al,* 1997). One would also attribute these climate changes to reorganizations of the ocean's thermohaline circulation, and to changes in tropical atmosphere-ocean dynamics (Broecker, 2003). The climate system itself also goes far beyond the physical world, and includes societal processes that change the atmosphere's composition and land surface (Lange *et al.*, 2008). Current scenarios of global climate change include predictions of increased upwelling and consequent cooling in temperate and subtropical upwelling zones (Aronson and Blake, 2001). The vagaries of ocean currents and cloud behaviour will undoubtedly lead to greater warming in some regions and even cooling in others (Helfman *et al.,* 1997).

Climate change adversely threatens global food security because drought and erratic precipitation would have negative impacts on fisheries and agriculture. Climate change will continue into the coming century at rates projected to be unprecedented in recent human history (Adger *et al.,* 2003). According to McMichael (1997), the expected rate of climate change over the coming century would be far greater than any natural change in world climate since the advent of agriculture, 10 000 years ago. While the initial emphasis has been on the "global picture," there has been an increasing urge to narrow the focus down to regional or even sub-regional investigations and assessments (Lange *et al.*, 2008). In terms of perturbations from climate change on local and regional scales, urbanization and land use changes are also important (Karl *et al.,* 2003).

Global Impacts And Evidence Of Climate Change

The impacts of climate change take different forms in both developing and developed countries. The impacts, among other factors, include: a rise in atmospheric temperature, melting of polar ice, increased water temperature, acidification of the ocean, a rise in sea level, altered precipitation patterns, erosion of fertile tracts of agricultural land, losses of human food, destruction of infrastructure, drying of lakes and rivers, and changes in fish biodiversity. Climate change also results in aridification, drought, floods, and high winds (Anneckle, 2002). Increased carbon dioxide is responsible for an increase in the acidity of seas and oceans, which will hurt corals as well as planktonic organisms at the base of the food chain. Ocean acidity will also have a negative impact on the development (ontogeny) of skeletal structures in aquatic organisms some of which may be fish food organisms. The viability of populations is however, influenced by such driving forces as density dependence and climate variability (Zabel *et al.,* 2006).

Water temperature variability can occur naturally or as a result of anthropogenic perturbations, such as thermal pollution, deforestation, flow modification and climate change (Caissie, 2006). Water temperature variability due to global warming would also result in changes in dissolved oxygen. It has been shown that a miss-match between the demand for oxygen and the capacity of oxygen supply to tissues is the first mechanism to restrict whole-animal tolerance to thermal extremes (Portner and Knust, 2007). A decrease in aerobic performance in warming seas will thus be the first process to cause extinction or relocation to cooler waters (Portner and Knust, 2007).

Changes in climate conditions and, possibly, weather variability would also affect human health through several processes, many mediated by disturbances of ecological systems (McMichael, 1997). Health effects from climate change will stem from: altered temperatures, extremes of precipitation (floods and droughts), air pollution, and infectious diseases (McMichael *et al.,* 2008). Although disease outbreaks are often influenced by local weather, how changes in disease trends might be affected by long-term global warming is more difficult to establish (Patz *et al.,* 2002). Recent advances may however, provide insight in predicting change in the risk of zoonotic disease, following climate shifts (Rossignol *et al.*, 2006). Many factors, including climate warming, can also contribute to disease outbreaks in marine life (Lafferty, Portner, and Ford, 2004). Populations would however, vary in their vulnerability because of differences in location, social and technical resources, and concurrent health status (McMichael, 1997). Health issues are applicable here, since human sickness (due to climate change) would obviously have a negative impact on fish production. Health professionals therefore, have a vital contributory role to prevent and reduce the health effects of global environmental change (McMichael *et al.*, 2008).

Since 1991, and in the past century, global sea level has risen by about 20 cm (King, 2004), or higher by 0.3 - 0.7m (Helfman *et al.,* 1997), partly from the melting of land ice or polar ice caps and partly from thermal expansion of the oceans. Temperature changes may provide evidence of climate change, as reported by Morrison, Quick and Foreman (2002) in Frazer River watershed where conditions matched trends in the historical record (1961-1990). Agricultural expansion may also have global environmental impacts. Aquatic nutrient eutrophication can lead to loss of biodiversity, outbreaks of nuisance species, shifts in the structure of food chains, and impairment of fisheries (Tilman, 1998), while an increase in ocean temperature may also be noted (Drinkwater, 2005). Higher air temperatures are expected to contribute to increased water temperatures, alterations in stream flow conditions, and ultimately reductions in fish growth (Swansburg *et al.,* 2002). At very high temperature, in shallow rivers, fish mortality would be expected. In particular, juvenile fish would experience either predictable or unpredictable changes in the rivers (Gaudin, 2001).

Vulnerability Of Developing Countries To The Impacts Of Climate Change

To discuss the impacts of climate change on fishes and their biodiversity in developing countries, we first need to understand characteristics of these countries that would easily make them vulnerable to impacts of climate change. Some of the most important impacts of global climate change will be felt among populations, predominantly in developing countries, referred to as "subsistence" or "smallholder" farmers (Morton, 2007).

Sources of vulnerability of developing countries to climate change include: greater reliance on agriculture for income, high dependence on subsistence agriculture, less protective infrastructure for coastal communities, existing land degradation and desertification, existing water scarcity, rapid rates of urbanization, high levels of poverty, high prevalence of HIV/AIDS, high rates of population growth, high rates of infectious diseases, absence of insurance infrastructure, and low levels of savings or absence of savings (Ramin, 2007). These climate impacts will affect vulnerable, low income populations first (Patz and Kovats, 2002). Wealthy, energy consuming nations are most responsible for emissions that cause global warming, yet poor countries are most at risk (Patz and Kovats, 2002), and their contribution to pollution of the atmosphere is very small. Developing countries are at risk because of their fragile economies, low human capacity, and inadequate infrastructure.

Another concern is that few of these developing countries can promptly handle emergencies triggered by climate change. Diseases also create another problem in developing countries. Since the Millennium Development Goals (MDGs) relate directly to health issues, climate change should be considered as a huge threat to global health (Ramin, 2007). Potential impacts of climate variability and change on water resources were illustrated by Muller (2007) in sub-Saharan Africa, one of the most affected regions. According to Mills (2005), climate change can also have adverse impacts on insurance affordability and availability, potentially slowing the growth of the industry and shifting more of the burden to governments and individuals. Societal vulnerability to the risks associated with climate change may exacerbate ongoing social and economic challenges, particularly for those parts of societies dependent on resources that are sensitive to changes in climate (Adger *et al.*, 2003).

Flooding is another problem emanating from climate change. Floods with the largest mortality impacts have occurred where infrastructure is poor and the population at risk has limited economic resources (Ahern *et al.,* 2005). Increased storm frequency and intensity related to climate change are also exacerbated by such local factors as the growing occupation of floodplains, increased runoff from hard surfaces, inadequate waste management and silted-up drainage (Douglas *et al.,* 2008). Some sectors are however, more sensitive and some groups in society more vulnerable to the risks posed by climate change than others (Adger *et al.,* 2003). Risks are apparent in agriculture, fisheries and many other components that constitute the livelihood of rural populations in developing countries (Adger *et al.*, 2003). In developing countries (including Malawi) the impact of climate change on their fisheries resources and fish biodiversity would therefore, be disastrous. A global assessment of the potential impact of climate change on world food supply has indicated that doubling the atmospheric carbon dioxide would lead to a small decrease in global crop production, but developing countries are likely to bear the brunt of the problem (Rosenzweig and Parry, 1994).

Most developing countries are also directly hit hard by poverty-driven problems. According to Waterson (2003), 1.3 billion people live on less than US $1 per day, and half the world's population, about 3 billion people, live on less than US $1.30 per day. Considering that this was reported about 5 years ago, the situation may have either improved or worsened further. Environmental degradation is another problem of developing countries. Poverty cannot however, be eliminated while environmental degradation exacerbates malnutrition, disease, and injury (McMichael *et al*, 2008). Civil strife is an additional problem that may broaden the impacts of climate change experienced in developing countries. After reviewing the potential impact of climate change on food security, Schmidhuber and Tubiello (2007) found that of the four main elements of food security (availability, stability, utilization, and access), only the first is routinely addressed in simulation studies. Food security would however, be meaningless if the available food is unstable, inadequately utilized and inaccessible.

Another point of deep concern is that developing countries may now be facing diminishing opportunities for industrial development. First, they need overseas development funds for national development, and additional funds for climate change-related research. Inadequate funding for research would prevent these countries from developing mitigation measures against local impact of climate change, and from formulating appropriate adaptation strategies. Secondly, the plans of poor countries to develop their own industries could be delayed by the process (which may take a long time) launched by the rich countries to develop alternative sources of energy, as a replacement for fossil fuels. The two problems would prevent developing countries from participating in the generation of new information on local impacts of climate change. The establishment of more industries may also be delayed in developing countries because of this problem.

Vulnerability Of Fishes And Their Biodiversity To The Impacts Of Climate Change

General impacts on fishes

Current global fisheries production of approximately 160 million tons is rising as a result of increases in aquaculture production (Brander, 2007). Aquaculture and stock enhancement are relied upon as the sectors to spur increases in fisheries production (Williams and Poh-Sze, 2003). Local extinctions of certain commercially important fish species are however, expected with high confidence (Easterling, 2007). For example, a linear regression of the data for the past 40 years yielded an excellent fit, with a predicted date of collapse of global fisheries by the year 2114

(Jaenike, 2007). Inland fisheries may also be threatened by human behaviour and faulty management.

Reducing fishing mortality in the majority of fisheries, is the principal feasible means of reducing the impacts of climate change (Brander, 2007). This is however, a fisheries management battle which seems to have already been lost at global level. Poulard and Blanchard (2005) reported an increasing abundance trend with time for fish species having a wide distribution range in latitude (mainly subtropical ones). In developing countries, drought would produce serious consequences on fisheries resources. In Lake Valencia (Venezuela), water level has been dropping for a long time (Curtis *et al.,* 1999), obviously at the detriment of available fish stocks. In Malawi, Lake Chilwa dries periodically, probably indicating an impact of climate change. When drought occurs due to climate change, receding river water forces fishes to assemble in small pools, but at high density, where fish mortality would escalate. Prolonged exposure of fishes to this harsh environment would result in reduced growth, reproduction, and dissolved oxygen, besides increased pollutant concentrations, stress, and diseases.

Fishes escaping from a drying lake into the rivers may however, be able to return when the lake refills. For example, in shallow endorheic lakes: Mweru Wa'Ntipa (Zambia) Ngami (Botswana) and Chilwa (Malawi), fish diversity rapidly increases by colonization from adjacent (relict) communities surviving in more permanent nearby water bodies, when filling starts (Jackson, 1989). The most frequently demonstrated effects of drought observed from 50 papers (Matthews and Marsh-Matthews, 2003) included: population declines, loss of habitat, changes in the community, negative effects from changes in water quality, movement within catchments, and crowding of fish in reduced microhabitats. Drought also causes shifts in the distribution of estuarine habitats (Helfman *et al.,* 1997). Ongoing studies of fish experiencing drought may however; aid in future conservation of what will become species at risk under climate-change scenarios (Matthews and Marsh-Matthews, 2003).

Reef fishes are also significant socially, nutritionally and economically, yet biologically they are vulnerable to both over-exploitation and degradation of their habitat (Sadovy, 2005). Various types of corals (submissive, foliose, brain, tabulate, massive, branching, encrusting, fire and mushroom corals), demonstrate a very rich diversity in colour, form and size. Coral reefs and mangroves are important fish nurseries; but higher sea surface temperatures may have already threatened and killed a large percentage of the globe's coral reefs. The greater the dependence species have on living coral as juvenile recruitment sites, the greater the observed decline in abundance. For example, bleached corals (due to high ocean temperatures) will contain fewer symbiotic algae and less photosynthetic pigment than unbleached corals. This would, in turn, reduce the energy stores of corals and lessens their ability to secrete a calcium carbonate skeleton (Helfman *et al.,* 1997). Under conditions expected in the 21st century, global warming and ocean acidification will therefore, compromise carbonate accretion, with corals becoming increasingly rare on reef systems, resulting in less diverse reef communities and carbonate reef structures that fail to be maintained (Guldberg *et al.,* 2007). This reduction in the secretion of calcium carbonate skeleton will adversely affect the ontogeny of reef fishes and corals.

For example, in Seychelles, climate change-driven loss of live coral, and ultimately structural complexity, have resulted in: local extinctions, substantial reductions in species richness, reduced taxonomic distinctness, and loss of species within key functional groups of reef fish (Graham *et al.*, 2006). Diversity, frequency, and scale of human impacts on coral reefs are also increasing to the extent that reefs are threatened globally (Hughes *et al.,* 2003). In addition, relative to other fisheries globally, those associated with coral reefs are under-managed, under-funded, under-monitored, and are poorly understood or little regarded by national governments (Sadovy, 2005). In this case, international integration of management strategies that support reef resilience needs to be vigorously implemented, and complemented by strong policy decisions to reduce the rate of global warming (Hughes *et al.,* 2003).

Estuarine habitats, and fish assemblages associated with them, are also adversely impacted by many anthropogenic influences which can have a direct influence on food resources, distribution, diversity, breeding, abundance, growth, survival and behaviour of both resident and migrant fish species (Whitfield and Elliot, 2002). In Malawi (a landlocked developing country), fishes in river estuaries may be adversely affected by anthropogenic impacts, and would therefore, need protection. For example, populations of valuable fishes of the genera: *Labeo* and *Opsaridium* could be wiped out by destructive fishing methods at the river mouth, especially when these fishes are ascending upstream to their spawning grounds. This could be one of several reasons for the disappearance of *Labeo s*pecies and other valuable fish species from the waters of some developing countries.

In Malawi, fish plays a pivotal role in nutrition, as it provides 60-70 % of the animal protein in human diets (MPRSP, 2002), contributes 36-40 % of total available dietary protein and 4 % of the country's GDP. Lake Malawi has about 850 fish species, with estimates rising up to 1000 species (Stauffer *et al.,* 1997), 90 % of which are endemic. According to Konings (2003), 800 of these are cichlid species. The impact of climate change on Malawi's dwindling fish stocks could therefore, not only be disastrous, but this would also become a new challenge.

In some developing countries, wrong land use in water-shed areas may also be detrimental to fisheries resources. The values of lacustrine, riverine, reservoir and floodplain fisheries could precipitously diminish due to wrong land use patterns in the water-shed areas of these ecosystems. Wang *et al.* (1997) reported a strong association between high urban land use with poor biotic integrity. Most of the world's large rivers are also fragmented by dams. Fragmentation of the river ecosystem alters migration patterns among fish populations, and converts free-flowing river to reservoir habitat (Jager *et al.,* 2001). Fishes may be adversely affected by the erection of these obstacles, unless the fishes are allowed free access to their spawning sites upstream.

Damming of rivers (normally done for good economic and food security reasons) may also have different impacts on different fish taxa. Data from Zambezi impoundments have indicated that the reaction of previously riverine fish to large man-made lakes has been for the previously sparse lentic taxa (*Oreochromis* species) to proliferate, and the lotic forms (*Labeo* species) to be reduced (Jackson, 1989). Dry-season flow rates in rivers would usually be slow in a number of developing countries, leading to reduced fish production. Increased runoff and discharge rates may however, either be injurious to juvenile fish or boost fish production through more extensive and prolonged inundation of floodplains. A study funded by NORCONSULT in Malawi (Likongwe and Sandlund-unpublished report) showed that fish catches in the Upper Shire benefited from high Lake Malawi levels, suggesting the beneficial effects of flooding on fish production.

High fish production would also be experienced by other developing countries if their large rivers receive more water from melting ice in response to global warming. According to Caissie (2006), information on thermal regime of rivers in relation to anthropogenic impacts will contribute to better protection of fish habitat and more efficient fisheries management. While global warming has enhanced some elements of productivity of shallow-water stocks and has reduced the productivity, and possibly the resilience, of the already slow-growing deep-water species (Thresher *et al.,* 2007), such global warming may also potentially shift the optimum temperature for aquaculture, to other areas (Stenevik and Sundby, 2007).

Continentally, warming would have another effect. It would contract the geographic ranges of cold-adapted fishes, while expanding the ranges of species that prefer warmer conditions (Helfman *et al.,* 1997). This may also suggest an expansion of the range of warm water aquaculture species, such as Tilapia. Also, with global warming, there may be a shift in geographical distribution of some fish species (Lanning *et al.,* 2003). Naturally, with global warming, high-altitude cold water fishes would experience a rise in water temperature. Even under temperate climatic conditions, high environmental temperature is reported to have triggered sexual maturity in *Brachyhypopomus pinnicaudatus* (Quintana *et al.,* 2004). Other researchers have also indicated that increased water temperature may also provide growth benefits in winter, but could threaten some fish populations living towards the upper end of their thermal tolerance zone in (late) summer (Morgan, GordMcDonald and Wood, 2001).

Fishes will normally move to new habitats under some form of stimulus. For example, in both elvers and juveniles, the key stimulus for their migration at the tidal limit was water temperature, with some weaker monthly influences related to seasonal temperature increases (White and Knights, 1997). The preferred reaction of fish to a temperature change is an escape reaction, implying activation of a sensorimotor pathway (van den Burg *et al.,* 2006). Higher air temperatures contribute to increased water temperatures, alterations in stream flow conditions, and ultimately reductions in fish growth (Swansburg *et al.*, 2002), especially if the temperature rises to values outside the upper tolerable range for the fish species in question.

The frequency and intensity of extreme climate events would therefore, likely have a major impact on future fisheries production in both inland and marine systems (Brander, 2007). Global warming also adversely affects key elements of human development. For example, aquatic ecosystems, human health, and socio-economic systems such as agriculture, forestry, fisheries and water resources, are the key elements of human development and well-being that are all sensitive to climate change (Tackle, 1997). The economies of Island States/Districts would be hit hard directly by the impacts of hurricanes, typhoons or El-Nino which may destroy infrastructure used for fishing.

Naturally, besides the impact of global warming, fishes would normally die on being subjected to several unfavourable (too high and too low) water quality parameters. The list of parameters causing mass fish mortalities can be long, but this review cannot exhaust them all. The marine capture fisheries also face major and complex challenges: habitat degradation, poor economic returns, and social hardships from depleted stocks, illegal fishing, and climate change, among others (Grafton *et al.,* 2008). Climate change and overexploitation are also increasingly causing unanticipated changes in marine ecosystems, such as higher variability in fish recruitment and shifts in species dominance (Cury *et al.,* 2008).

Inland fisheries are additionally threatened by changes in precipitation and water management (Brander, 2007). There are some interactions between the effects of fishing and those of climate. For example, it has been stated that fishing reduces the age, size, and geographic diversity of populations and the biodiversity of marine ecosystems, making both more sensitive to additional stresses such as climate change (Brander, 2007). The lasting detrimental effects on fish populations have however, been limited to areas where native populations have declined, and have become increasingly isolated because of anthropogenic activities (Gresswell, 1999). This habitat alteration has probably the greatest impact on individual organisms and local populations that are least mobile, and reinvasion will be most rapid by aquatic organisms with high mobility (Gresswell, 1999).

It will also be important to consider governance issues in the management of marine ecosystems. Potential gains from this option would include: restored habitats, biodiversity conservation, larger fish stocks, greater returns to fisheries and their communities, increased food security, and poverty alleviation (Grafton *et al*, 2008). Predictions for coastal marine areas include changes in air and sea temperatures, ocean currents, atmospheric storms, freshwater inputs from land and sea level (Lafferty *et al*, 2004). Many autecological effects of temperature on fish are known, and fishery biologists have begun to incorporate this knowledge into population-level relations that can be used to assess possible effects of climatic warming on fishes and their habitats (Tonn, 1990). Negative impacts of climate warming will be strongest on species diversity (Helfman *et al.,* 1997). This would be understood after assessing the following impacts of global changes in the environment: freshwater shortages, loss of biodiversity (with consequent changes to functioning of ecosystems), and exhaustion of fisheries (McMichael *et al.,* 2008).

An increase in water temperature results in a reduction in dissolved oxygen. According to Portner and Knust (2007), a miss-match between the demand for oxygen and the capacity of oxygen supply to tissues is the first mechanism that will restrict whole-animal tolerance to thermal extremes. The importance of oxygen as an ecological factor for maintaining populations of fisheries-related species cannot be overemphasized (Diaz, 2001). Decreases in aerobic performance in warming seas will be the first process causing extinction or relocation to cooler waters (Portner and Knust, 2007). Oxygen deficiency (hypoxia and anoxia) is therefore, easily understood as one of the factors producing a widespread anthropogenically-induced deleterious effect on fishes. Impacts of climate change would worsen deoxygenation.

Impacts on fish biodiversity

Biodiversity or biological diversity may be defined as a “variety and variability among living organisms and the ecological complexes in which they occur” (Angermeier and Karr, 1994). It is characterized by the number (richness) and relative abundance (evenness) of species. One would estimate biodiversity of an area by counting all taxonomic, genetic, and ecological elements present, but we are constantly losing this biodiversity. The current massive degradation of habitat and extinction of species is taking place on a catastrophically short timescale (Novacek and Cleland, 2001).

Fish biodiversity can be impacted by several factors including: poor water quality, population loss due to mortality, reproductive failure, hybridization, loss of genetic diversity, coral reef destruction, poisons, bottom trawling, dam construction, watershed perturbations, deforestation of riparian trees, rise in water temperature, silting from erosion, collapse of stream banks, competition for water, species introductions, over fishing, burning of vegetation, surface water withdrawal, overgrazing, livestock movements, changes in river discharge, floods from heavy precipitation, flash floods, drought, disease outbreaks, pollution, destructive species, population explosions of destructive species, narrow range of temperature tolerance, deoxygenation, silt covering eggs, eggs being washed away, juveniles being flushes away, riffles filled with debris, lack of behavioural avoidance capabilities, low water flow leading to isolated pools, increased ecological interactions (fish crowding together in a small area), desiccation, upland fishes moving downstream as rivers dry, floodplain fishes moving into the main river, increased species diversity during low water, predation reducing fish diversity, extreme weather, high speed cyclones, hurricanes or typhoons, high waves that break coral reef environments, massive corals that are broken off, storms changing species distribution, sand causing wounds on fish bodies, fish kills, and biological interactions (Helfman *et al.,* 1997).

Human-dominated marine ecosystems are also experiencing accelerating loss of populations and species, with largely unknown consequences (Worm *et al.*, 2006). For example, human impacts have depleted >90% of formerly important species, destroyed >65% of sea grass and wetland habitat, degraded water quality, and accelerated species invasions (Lotze *et al.*, 2006). Two types of diversity: alpha diversity (the number of species within a habitat) and (2) beta diversity (the change or turnover in species across space) were reported by Samson and Knoff (1993). Aquatic nutrient eutrophication can also lead to loss of biodiversity, outbreaks of nuisance species, shifts in the structure of food chains, and impairment of fisheries (Tilman, 1998). Marine biodiversity loss is increasingly impairing the ocean's capacity to provide food, maintain water quality, and recover from perturbations, but restoration of biodiversity is reported to have increased productivity fourfold and decreased variability by 21%, on average (Worm *et al.,* 2006).

Conservation of biodiversity is important, since according to Carabias (2003), biodiversity provides food, medicines, fibers, fertile soil, clean water, regulation of hydrological cycle, regulation of local air temperatures, and balance of atmospheric gases that determine climate of the planet. The protection of riverine fishes and their biodiversity, would however, depend on a solid knowledge of the species concerned (Bless, 2001). Developing countries need to know and protect biodiversity of their valuable riverine fish stocks, considering that these fishes would also be vulnerable to climate change. Preliminary studies on the riverine fishes of Malawi (Likongwe, 2005) revealed variable levels of biodiversity. This biodiversity would be lost, following the impact of climate change (drought). Developing countries should naturally be worried about losses of their fish biodiversity. They should worry because rates of extinction and endangerment for aquatic fauna exceed those for terrestrial fauna (Angermeier and Karr, 1994).

Rose (2005) reported that both latitude and depth are negatively correlated with species number and density. This may suggest spatial variations in impacts in different countries.). The spread of exotic species and climate change are also among the most serious global environmental threats (Stachowicz *et al.,* 2002). Global change, land use change, changing commercial trade intensity and pathways, changes in atmospheric composition, including CO_2 and nitrogen deposition are all predicted to aid the establishment of alien invasive species (Mooney and Hofgaard, 1999). In Malawi, exotic fish introductions are banned to protect the rich fish biodiversity of one of the Great Lakes of Africa: Lake Malawi. This lake is surrounded by three riparian countries, so monitoring of this ban is important. Scientists have stated that certain threats to biodiversity require intensive international cooperation and input from the scientific community to mitigate their harmful effects, including climate change and alteration of global biogeochemical cycles (Novacek and Cleland, 2001).

The introduction of Nile perch into Lake Victoria resulted in losses of fish species diversity (Ogutu-Ohwayo, 1999), while the introduction of water hyacinth into the same lake caused deterioration of water quality (Kudoja, 1998). Impson and Hamman (2000) also observed highly threatened freshwater fishes in the Western Cape Province of South Africa, where nine (9) of the 13 species endemic to river systems were endangered or critically endangered. Changes in riverine fish biodiversity have also been reported in the Nile River, Egypt, which had 74 species, but 14 of these disappeared (Bishai, 1998).

Certain important abiotic-biotic factors however, also regulate, to a large extent, a continuum of fish communities in rivers (Zalewaski *et al.*, 1984). Introductions of new species can have genetic impacts. These impacts can be defined not only as alterations in the gene pool of native fishes, but also as alterations in the introduced populations themselves (Agnese, 1997). Climate change may therefore, exert its impact on fishes that have an altered gene pool.

Although introductions of exotic species are detrimental to native species, Hoyt (1992) reiterated that the great bulk of human dietary needs are met by species that have been introduced from elsewhere. This statement may have been an expression of opinion, rather than one intended to influence changes in the existing fisheries policies of developing countries. A restricted geographic distribution of fish is also a factor contributing to species vulnerability to anthropogenic causes of extinction within freshwater fish assemblages (Hugueny and Teugels, 1998). It has been shown that man's activities have profound, and usually negative influences on freshwater fishes (Karr, 1981), and loss of endemic species will also represent a symptom of general degrading ecosystem conditions, which is a result of biodiversity alteration (Oberdoff *et al.,* 1999).

In nature, since evaporation and CO_2 balance at the ocean surface are temperature-dependent (Tackle, 1997), changes in sea temperature would severely affect marine ecosystems and productivity (Nyong, 2005). Water temperature variability can also occur either naturally or as a result of anthropogenic perturbations, such as thermal pollution, deforestation, flow modification and climate change (Caissie, 2006). Also, the existing marine reserves are largely ineffective, and as a whole, remain insufficient for the protection of coral reef diversity (Mora *et al.,* 2006). According to Sadovy (2005) reef fish fisheries and conserving biodiversity can be complementary, rather than contradictory, in terms of yield from reef systems.

Trees are also important in the management of fisheries. Deforestation exposes rivers to direct sunlight which raises the water temperature. In elevated water temperature, growth of fish may either increase or decrease, depending on the tolerable thermal limits of these fishes. Bare ground is also quickly eroded during heavy precipitation. The silt load that is washed down-slopes reaches the river banks where it may damage (cover) fish eggs and juveniles, and destroy potential fish spawning sites. Aquatic biota will also respond to the concentration of suspended sediments, but evaluation of suspended sediment in aquatic environments should also include duration of exposure (Newcombe and Macdonald, 1991). The importance of trees cannot therefore, be questionable: they support the construction industry, provide energy, medicines, and are used for other domestic purposes. This is why developing countries have to implement intensive re-afforestation programmes to replace trees. Massive removal of trees (without replacement) could also usher in desertification.

In lakes and rivers, climate change will increase water temperatures, flow conditions, and water levels which, in turn, would affect species survival, reproduction and growth (Tackle, 1997), in addition to the effects of deforestation. Little of the vast literature on temperature physiology of freshwater fish is useful in predicting the effects of global warming (Morgan *et al.,* 2001). Further thermal studies on fishes may be needed to show potential impacts of global warming on lacustrine, riverine and aquaculture fishes in various agro-ecological zones of Africa.

Mitigation And Adaptation

Developing countries need urgent mitigation and adaptation formulae against the ongoing and future impacts of climate change on their fisheries resources. Lange *et al.* (2008) have stated that when addressing the consequences of climate change and possible mitigation and adaptation, economics or sociology have to be consulted to come up with results that are more than "academic". More systemic changes in resource allocation need to be considered, such as targeted diversification of production systems and livelihoods, bearing in mind that multidisciplinary problems require multidisciplinary solutions i.e., a focus on integrated rather than disciplinary science and a strengthening of the interface with decision makers (Howden *et al.,* 2007). The challenge is to promote adaptive capacity in the context of competing sustainable development objectives (Adger *et al.*, 2003). This is a holistic process for integrating and delivering, in a balanced way, the three objectives of the Convention on Biological Diversity (CBD): conservation, sustainable use of biodiversity and equitable sharing of the benefits (Maltby, 1999). Institutional change that aligns private with public interests and builds on the experiences of successful fisheries governance can position fisheries in a changing world (Cury *et al.,* 2008).

An attempt to achieve increased adaptation action will also necessitate integration of climate change-related issues with other risk factors, such as climate variability and market risk, and with other policy domains, such as sustainable development (Howden *et al,* 2007). In some countries, action to help poor urban communities adapt and to become more resilient to possible change must be initiated, although to date, attention has focused on mitigation rather than adaptation (Muller, 2007). Also, a crucial component is the implementation of adaptation assessment frameworks that are relevant, robust, and easily operated by all stakeholders, practitioners, policymakers, and scientists (Howden *et al.,* 2007).

Seeing a film, in the short term, is reported to have changed people's attitudes: viewers were significantly more concerned about climate change, and about other environmental risks (Lowe *et al.*, 2006). While local people adapt to floods, the recognition of local, national and international governments' and organizations' responsibility to act to alleviate flooding and its causes, especially the consequences of climate change, is urgently needed (Douglas *et al.*, 2008). Issues of successful adaptation cannot run away from funding. Developed countries should kindly consider funding research in developing countries where studies can build resilience after the impacts of "climate change". According to Muller (2007), this funding should be made available in terms of the "polluter pays" principle, and should be channeled through government budgets. It has been observed that social and ecological vulnerability to disasters and outcomes of any particular extreme event are influenced by the buildup or erosion of resilience both before and after disasters occur (Adger *et al.,* 2005). Wherever possible therefore, nations should be proactive by developing or procuring gadgets for more effective early warning systems. Since poverty and lack of highly advanced technological capabilities (capacity) are characteristics of most developing countries, urgent financial support is needed to support the adaptation process after an emergency. Nations (through Institutions) could also produce human capacity, sensitize rural communities on impacts of climate change, produce realistic climate change models, facilitate research, and impart appropriate knowledge to students at all levels, through the normal educational systems.

Ecosystem Approach

Modern fisheries management is based on scientific advice for setting catch limits for exploited fish stocks and different measures for controlling the fisheries (Bjordal, 1999). Community participation in coastal fisheries management (Sharma, 1999) seems to be an approach similar to co-management used in Malawi. It is accepted by governments, development agencies, NGOs, and people's movements alike that local communities should participate in management, especially in coastal fisheries resources (Sharma, 1999). In Malawi, the Environmental Management Act (1996) emphasizes the need to protect and manage the environment, conserve natural resources, and promote sustainable utilization of these resources. Countries also establish national reserves for efficient protection of their aquatic wealth. For these reserve networks to succeed however, social acceptance, adequate enforcement, and effective scientific evaluation will be required (Murray *et al.*, 1999).

Even well-designed reserve networks will however, require continued conservation effort outside reserve boundaries to be effective (Murray *et al.,* 1999). The traditional focus of conservation on species, protected areas and environmental legislation has generated considerable conservation action, but genes, species, and ecosystems are still being lost at an accelerating pace (McNeely, 1999). Ecosystem management works to guide, rather than thwart natural processes (Sparks, 1995), and managing ecosystems for societal benefit also means managing diversity *per se* (Mooney, 1999). Global environment facility (GEF)-supported programmes have so far focused almost exclusively on conservation of biodiversity through protected areas (Gadgil, 1999). In Malawi, a similar arrangement was established at the "Lake Malawi and Liwonde National Parks".

Twelve (12) Malawi principles of an ecosystem approach (Prins, 1999) would also be important, as they recognize that humans are an integral component of ecosystems. Elsewhere, these principles offer insights into connections between people and marine ecosystems (Hanna, 1999). To achieve the hunger-and malnutrition-related Millennium Development Goals, we need to address poverty, associated with the insecure supply of food and nutrition (Muller and Krawinkel, 2005). This will help to save lives and develop alternative employment opportunities. Funding from rich countries would help developing countries to improve human capacity, develop effective outreach programmes, and make communities better prepared in their fight against the impacts of global warming.

Conclusion

To reduce the impacts of climate change on fisheries, nations may decide to re-examine their existing fisheries management agenda. Modeling of future impacts of climate change (beyond dry-season effects), and an understanding of potential effects of flooding and drought on fisheries may be needed. Nations should continue protecting their aquatic environments, sensitizing their own citizens on the impacts of climate change, and identifying alternative sources of livelihood to be used when economically-valuable fisheries resources have been destroyed. Education and training are national tools used for building sustainable human capacity. Although citizens of developing countries have already painfully started learning to cope with the impacts of climate change (drought, floods and strong winds), citizens of these countries still need to be trained to adapt more successfully after future impacts of climate change.

An example of adaptation was reported after the Indian Ocean disaster (Miller, 2005). In Sri Lanka, victims also identified their own coping aids after the impact of climate change (Hollifield *et al.,* 2008). Methods of sustainable disaster relief and management were also identified by Mathbor (2007). Failure to address climate change-related problems would inevitably lead humans to growing poverty, hardship and social unrest in many areas (Sadovy, 2005). It is very clear that global impacts of climate change on fisheries would be disastrous for millions of people who depend on fisheries for their food security and employment in developing countries. These impacts would add negatively to the already dwindling world fish stocks, and widen the level of poverty.

Way Forward

Finally, as a way forward, there are fifteen (15) key climate-change related questions that require serious deliberations, and solutions from the entire global community: (1) how can we precisely visualize the exact impacts of future trends in climate change? (2) how can we succeed in getting the main (greenhouse gas emitting) nations to honour the Kyoto Protocol on climate change? (3) how can developing countries quickly develop their own industries, while the rich nations are slowly developing effective substitutes for fossil fuels? (4) how sure are we that all nations will voluntarily and seriously start conserving and protecting the global forest cover, coral reefs and mangroves to enhance the carbon dioxide absorption capacity of these ecosystems? (5) how effectively would developing countries build their research/technical capabilities as a mitigation tool for reducing future impacts of climate change? (6) with climate change being a very important emerging issue for all humanity, would developing countries now consider “climate change, impacts, adaptation and resilience” as necessary components of the school/college curricula? (7) how have rural communities painfully and successfully dealt with previous impacts of climate change (floods, drought, strong winds), and what can we learn from them? (8) how could we find a way of developing improved adaptation strategies and build resilience among our rural communities? (9) how can we produce realistic models or simulations of future impacts of global climate change? (10) how would fisheries scientists compare gradual adaptation (acclimatization) of fishes to a gradual rise in water temperature in laboratory experimental tanks, with the adaptation of the same fish species to a gradual rise in temperature due to global warming? (11) is it not possible, through a well-designed study, to assemble and document life-time (60 years+)

evidence and specific impacts of global warming among communities in our countries? (12) how could we compare the impacts of daily environmental perturbations, seasonal environmental changes and the unpredictable long-term climate change on fishes? (13) how could we locally assemble and use a multicomponent approach to mitigate the impacts of climate change? (14) with an increase in human population, how could we reduce land degradation in the water-shed areas to protect our fisheries resources? and (15) is it possible for developing countries across different climate categories to share technical information, resources and capacity to reduce the impacts of climate change? As Karl, Kevin and Trenberth (2003) put it: "we are venturing into the unknown with climate, and its associated impacts could be quite disruptive". By taking an immediate action against the impacts of climate change, human beings could successfully save themselves and other forms of life on the face of this globe".

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Subtheme 2:

Conservation of Biodiversity and Sustainable Agricultural Production

11. Agro biodiversity and Climate Change: What do Students Need to Know?

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Abstract

Agro biodiversity sustains livelihoods in Africa but is threatened by, among others, habitat degradation, land use changes, agricultural intensification, climate change, over-harvesting and loss of useful wild species, invasive species. Adaptation of production systems and society to climate change requires human capacity in agrobiodiversity but a 2007 survey in African universities showed that education in this area is weak or absent. Scientists predict a warmer climate across Africa, with significantly less rainfall in some areas like Southern Africa, or more rainfall in pockets of Eastern Africa leading to changing crop suitability patterns, loss of species, disappearance of marginal plant populations and altered distribution patterns of pests and diseases. The role of agrobiodiversity in adaptation to climate change must be better understood and recognized. Areas of competence include, among others: Biophysical and socioeconomic drivers and change in major components of agrobiodiversity including crops, wild crop relatives, trees, animals, fish, microbes; *In situ* and *ex situ* conservation and on-farm management of agrobiodiversity; breeding for resistance to abiotic and biotic stresses; enhancing links between gene banks, breeders and farmers; policy implementation, and the role of local knowledge. Agriculture extension will need to work with farmers on the substitution of species and varieties adapted to the emerging climate. Farmers need information on new pests and diseases, and how to prepare for long-term effects and short-term effects of climate change. Universities should review curricula to include agrobiodiversity dimensions in teaching of climate change. Innovative, experiential teaching methods and active student participation would help institutionalize holistic and action-oriented learning. Education must be research-driven to incorporate a rapidly growing knowledge base on agrobiodiversity and climate change.

Key words: agrobiodiversity, climate change, crop suitability, plant breeding, curriculum development

Introduction

Agro biodiversity – the sub-set of biodiversity important to food and agriculture – is a surprisingly recent concept. The Convention of Biological Diversity (CBD) for the first time specifically addressed agrobiodiversity in 1996 (CBD, 1996). In consequence, universities and colleges have just began including agrobiodiversity in agriculture curricula. The recent surge in food prices and the threats of climate change to food and livelihood security have brought agrobiodiversity into focus, calling for accelerated mainstreaming of agrobiodiversity in Africa's universities and colleges. Learning about agrobiodiversity in the context of climate change adaptation in Africa obviously requires that universities cover both areas. However, both agrobiodiversity and climate change currently get limited attention in most curricula. This paper therefore gives a broad review of agrobiodiversity as a preparation for its discussion on climate change adaptation. We suggest that competences to be developed in university programmes and courses might include, among others:

- Agro biodiversity: what it is, how it has evolved, and its functions for livelihoods and landscapes
- Processes influencing land use change in agro ecosystems, including human, economic, policy and environmental drivers
- Processes affecting the provision of ecosystem services and functions in agro-ecosystems
- Impact of land use change on agrobiodiversity at ecosystems, species and within-species levels
- Climate change and variability predictions for different sub-regions in Africa
- Impact of projected climate change on components of agrobiodiversity, including crop suitability projections
- Adaptation to climate change: agrobiodiversity options
- Approaches for putting adaptation strategies into practice in research, extension and policy implementation.

Reviewing curricula will not be enough to achieve this: teaching agrobiodiversity also calls for a critical look at the teaching and learning approaches in use. Because the topic is dynamic, system-oriented and multi-disciplinary, and because of uncertainty and a rapidly evolving knowledge base, traditional teacher-centered methods need to give way to more learner-oriented, participatory and innovative approaches to education.

What is Agricultural Biodiversity and how is it Taught?

Agricultural biodiversity is described as: 'a broad term that includes all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute the agro-ecosystem: the variety and variability of animals, plants and micro-organisms, at the genetic, species and ecosystem levels, which are necessary to sustain key functions of the agro-ecosystem, its structure and processes' (CBD, 2000). Agro biodiversity has spatial, temporal and scale dimensions. There is a dynamic change of agro ecosystems in time and space, shaped by interactions between genetic resources, the environment and people (FAO 1999). In Africa, communities traditionally used a very wide range of species and varieties for their food, nutritional and livelihood security, reflecting Africa's extremely diverse environment and cultural heritage. These genetic resources include traditional plant and animal varieties – landraces – domesticated by farmers, wild species harvested from forests, rangelands, wetlands and aquatic/marine ecosystems, as well as wild crop relatives. An estimated 7000 plant species have been used for food or animal feed globally at one time or other, and some 150 are commercialized at a global scale Thirty crops provide 95% of our food energy and only three crops – maize, wheat and rice – provide half of our calorie and protein intake (Wilson, 1992). Meanwhile, hundreds of underutilized plant and animal species continue to be important locally or sub-regionally, in particular for poor communities in marginal areas. In Kenya alone, about 800 wild plants are recorded to be used for food (Maundu, 1996). Such species tend to be neglected by scientists, policy makers and practitioners and their diversity is rapidly being lost along with farmers' local knowledge about them.

Agriculture policies and institutions, including higher education institutions, have largely focused on major stable crops and a few animal species. Agriculture education in Africa has largely concentrated on cultivating these few species in agricultural systems based on modern cultivars, monocultures and high inputs. Universities and colleges have therefore paid relatively limited attention to agrobiodiversity, including its maintenance and use, agro-ecosystem properties and functions, the role of farmers' traditional varieties, and the socio-economic and cultural processes that shape agrobiodiversity. This is now starting to change. Some systems-oriented subjects that recently have been introduced in university curricula, such as integrated pest management, agroforestry and watershed management. Participatory approaches are increasingly taught. The mainstreaming of agrobiodiversity education can build on such experiences.

How is agrobiodiversity taught: examples from Eastern and Southern Africa

In 2007 Bioversity International commissioned a survey to evaluate how plant genetic resources and agrobiodiversity are being taught in universities in eastern and southern Africa (Muluvi *et al*., 2008). The survey comprised of an electronic questionnaire distributed to 50 institutions, and in-depth interviews conducted during personal visits to nine universities in Kenya, Zimbabwe, Malawi, Zambia and Uganda. There was a very poor response rate for the electronic survey; the responding universities were those the consultant also visited. (The links between agrobiodiversity and climate change were not specifically addressed by the survey). Master's programmes on plant genetic resources (PGR) are taught in several universities, including:

- MSc Biotechnology (Kenyatta University and Jomo Kenyatta University of Agriculture and Technology (JKUAT) both in Kenya)
- MSc Seed Science (Moi University, Kenya and Makerere University, Uganda)
- MSc Horticulture (Kenyatta University, Egerton University and University of Nairobi, all in Kenya)
- Makerere University also offers an MSc in Crop science, with an option in plant genetic resources or plant breeding/genetics

All these programmes offer significant Plant Genetic Resource content with courses on genetics, plant breeding and seed production, among others, but very little agrobiodiversity learning. A notable exception is Kenyatta University which offers an MSc in Ethnobotany, a programme which presumably includes significant socio-cultural aspects of agrobiodiversity. In contrast, none of the nine surveyed universities offer a comprehensive agrobiodiversity programmes at undergraduate or graduate level. At BSc level, the study found limited agrobiodiversity content in only three programmes:

- Copperbelt University in Zambia incorporates a course on biodiversity conservation in its BSc Agroforestry programme
- JKUAT offers undergraduate students a course on ethnobotany in its Botany programme
- Egerton University in Kenya offers a course on traditional vegetables production with the BSc Horticulture programme

In six of the universities surveyed, the agrobiodiversity concept seems absent in their undergraduate programmes. Most programmes, regardless of level, are oriented towards a specific discipline, e.g., seed science, crop protection, agricultural economics, horticulture, microbiology, and agronomy. At the postgraduate level, the universities' agricultural programmes are typically (though not exclusively) thematically focused and quite technical. This implies less scope for addressing the holistic and multidisciplinary elements of agrobiodiversity.

All the universities surveyed – with the exception of the University of Zambia, and to a lesser degree Makerere University – expressed dissatisfaction with the way both agrobiodiversity and plant genetic resources are being taught. When asked about learning material dedicated to agrobiodiversity, all universities assessed their 'content quality' as inadequate.

The survey established that all responding universities engage in curricula review on a regular basis. Usually initiated by departmental staff as a response to industry and market demands, it involves a large number of stakeholders from academia, employers, farmers, government ministries, and research organizations. Draft documents are then tabled for university Senate approval. This suggests that with sufficient sensitization, staff might be encouraged to propose a curriculum review which incorporates an increased focus on agrobiodiversity. However, it is unclear whether there is existing job market and employer demand for these new skills and knowledge. The job market is predominantly comprised of public sector institutions, including ministries of agriculture, forestry departments, national gene banks and the wider national agricultural research system. Since universities offer programmes in disciplines for which there has traditionally been solid demand for graduate, courses tend to be fact-based, pragmatic and 'hard sciences' oriented. Without questioning the importance of these characteristics, this suggest that many programmes are not multi-disciplinary in scope, are reductionist as opposed to systems-oriented, and possibly lend themselves less to the development of 'soft skills'. These are all additional capacities which are urgently required in today's graduates in order to tackle emergent, complex and multi-stakeholder agricultural and environmental problems, such as the adaptation to climate change.

The survey results recommend promoting agrobiodiversity learning using a three-pronged strategy: Introducing elements of agrobiodiversity in existing courses and programmes opportunistically, in a manner that does not always require a formal curriculum re-think. This pragmatic way of introducing new content quickly and efficiently requires training of teaching staff and availability of effective teaching materials on agrobiodiversity. Secondly, universities could be supported to mainstream agrobiodiversity education in their range of BSc and MSc programmes in connection with the next cycle of curriculum reviews. Basic knowledge on agrobiodiversity should be acquired by all agriculture and forestry graduates. Thirdly, in the medium term perspective, universities could consider developing tailor-made agrobiodiversity options or specializations within existing Masters degrees. On a more distant horizon, the possibility of a full-fledged postgraduate programme in agrobiodiversity – perhaps developed through university partnership and offered through a regional centre of excellence – remains an interesting possibility. Such programme must emphasize the economic, social and environmental importance of agrobiodiversity, and attempt to connect this to future employment opportunities.

What is happening to Agro biodiversity in Africa?

Functions of agrobiodiversity

The contribution of agrobiodiversity towards food and livelihood security among poor African small-holders is increasingly recognized. Benefits of agrobiodiversity include, among others, risk mitigation, income generation, health and nutrition, ecosystems resilience, and cultural and aesthetical values.

Risk mitigation: Farmers, especially those using low-input farming systems, use plants, animal, fish and forestry diversity (both within and between species variation) to mitigate risks arising from droughts, pests and diseases or from volatile markets. Many resource-poor farmers plant genetically heterogeneous crops to minimize risk of crop failures (FAO 1996). Agrobiodiversity can therefore act as a 'safety net' in farmers livelihood strategies. For example, farmers may turn to forest ecosystems as a source of food and medicines in times of crisis.

Income generation: Traditional crop varieties, indigenous fruits, trees on farms, medicinal species, etc., can generate enhanced or new sources of income through their commercialization. The rapid growth of speciality crops and niche markets create new opportunities for farmers to gainfully participate in markets.

Health and nutrition: Agrobiodiversity contribute in many ways to health and nutrition by providing food and access to traditional medicines. A diet rich in iron and micro-nutrients is essential to avoid 'hidden hunger'. The nutritional properties of traditional food are here gaining attention.

Ecosystems resilience: Agrobiodiversity is essential to functional agroecosystems and good soil and water management. Soil organisms contribute to nutrient cycling, soil carbon sequestration, soil physical structure and water regimes, and influence on plant life (e.g. nitrogen fixation and interactions in the soil of pests, predators and other organisms). Pollinators are essential for crop and fruit production and their number and diversity can profoundly affect crop production levels. Payment schemes for environmental services now start recognize such values.

Cultural and aesthetic values: Rural landscapes have important cultural and aesthetic values, both for local people and for society at large, values that are threatened by rapid changes of agroecosystems. On the other hand, the growth of eco-tourism is a fast increasing source of income from agroecosystems.

Threats to agrobiodiversity

The loss of agrobiodiversity and associated local knowledge is rampant. The public debate on biodiversity loss tends to focus on 'wild' biodiversity: the threats to ecosystems, such as the reduction of forest areas, wetlands or coral reefs; or the loss of species, as reported in the IUCN Red List of Threatened Species (IUCN, 2008). There is much less concern with the loss of genetic diversity within agro ecosystems: the loss of genetic diversity that can occur when farmers substitute modern cultivars for traditional varieties, when crop wild relatives are being threatened, or when marginal populations of a species are lost. Although gene banks play an important part in conserving much of the crop diversity as well as that of crop wild relatives, they too can suffer problems of genetic erosion through inadequate resources and poor maintenance conditions. The recent opening, in February 2008, of the Svalbard Global Seed Vault brought these issues to global attention (Global Crop Diversity Trust, 2008).

While much of the discussion in this paper focus on crops, it is important to emphasize that similar patterns apply also to other types of agrobiodiversity. For example, according to FAO estimates, around 20 percent of reported livestock breeds are classified as at risk, and 62 breeds became extinct during a 6-year period (FAO, 2007).

Many threats to agro ecosystems and agrobiodiversity are well-known; others are more recent and less recognized. Climate change will accelerate many of these processes. Key drivers of change in agrobiodiversity in SSA include:

- Population growth: The population in SSA will increase from 769 million in 2005, to between 1,518 and 2,022 in 2050, according to forecasts by the United Nations (2006). Given no change in consumption patterns, the demand for agrobiodiversity products and services will double, or more, in the next 45 years. This will put tremendous pressure on agro ecosystems to producing more and better food, while sustaining the environment.
- Land conversion: Urban expansion causes wide-spread loss of agricultural land. The loss of forests and other wooded land in Africa continues at a rate of 4.4 million hectares, or 0.62 % per year (FAO, 2005). The promotion and expansion of biofuel production, such as *Jatropha curcas*, across Africa is also fast converting land from other uses .
- Land degradation and desertification results in the loss of agricultural area and productivity. In Africa, the degradation and loss of forest and bush land was found to be a main cause of loss of genetic resources (FAO, 1996).
- Changing agricultural practices associated with intensification of production, the introduction of mechanization and the use of agro-chemicals, leading to marginalization of traditional production systems (FAO, 2007). Promotion of a single approach to agricultural development, – e.g. the Green Revolution approach – is one of the most fundamental causes of agrobiodiversity loss (FAO, 1999). 'Neglected and underutilized crops' and traditional varieties are now getting more recognition, but much more research, resources and capacity is needed to enhance their conservation, use and commercialization.

The rise of supermarkets in Africa is having profound impact on agricultural production systems.

- Supermarkets use specialized wholesalers in their procurement and demand tough quality and safety standards (Weatherspoon and Reardon, 2003). This may exclude many small-scale farmers who trade small quantities of variable produce. On the other hand, supermarkets can also be a new opportunity for adding value to agrobiodiversity, as in the successful Africa Leafy Vegetable project (Oniang'o *et al*., 2006).
- Changing food habits have far-reaching implications on what farmers produce, such as the on-going shift from traditional food to carbohydrate-rich fast food, and increased meat consumption among a growing African middle class.

These trends can be devastating for small-scale farmers in Africa because loss of agrobiodiversity results in the loss of many products (food, fuel, medicines, building materials, living fences and so on) which are used as part of farmers' livelihood strategies as well affecting ecosystem function. Loss of agrobiodiversity can also result in a substantial decrease in the resilience of farmers' agro ecosystems and consequently increase in farmers' vulnerability. When change occurs, resilience provides the components for renewal and reorganization. When ecosystem loses its resilience, adaptation to change is not possible and therefore, change inevitably has potentially disastrous consequences. Inability to cope with risks, stresses and shocks, substantially undermines livelihoods of small-scale farmers. It is worth noting that the recent IPCC report particularly noted loss of ecosystem resilience as likely consequence of climate change (IPCC, 2007; Figure 11.1).

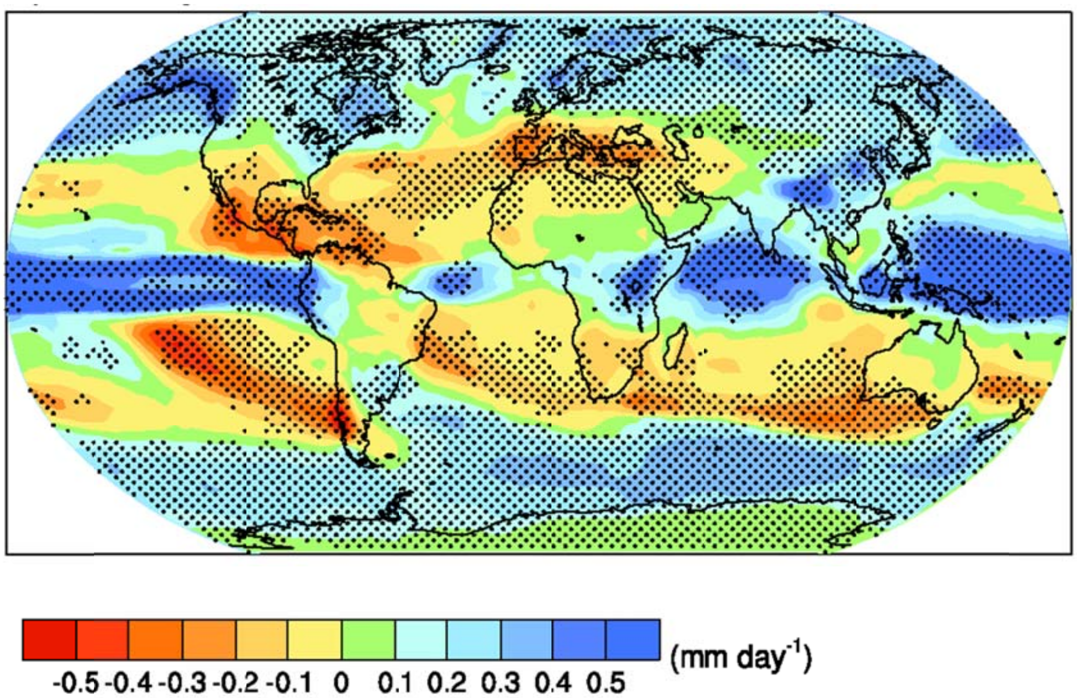

Figure 11.1. Change in rainfall climate according to the IPCC 4th Assessment (2007).

How is a Changing Climate Expected to Influence Agricultural Biodiversity?

The Fourth Assessment IPCC report (2007) predicts widespread increases in temperature across the globe, along with changes in rainfall regimes over the next 100 years and beyond. Models suggest both a change in the baseline, along with a change in the variability within years and between years, although varying levels of uncertainty should be attributed to predictions. Specifically for Africa, mean annual temperature is expected to increase 3-4°C to 2080-2099 (Christensen *et al.,* 2007). Rainfall is predicted to increase (with high agreement between models) in Eastern Africa by around +7 %, specifically around the highlands in Kenya, Uganda and Rwanda, and there is growing consensus that Southern Africa will become significantly dryer with predicted 30 % decreases in the winter period (Christensen *et al.,* 2007). There is no agreement between models as to the future of the Sahel, with both increases and decreases in rainfall predicted by the different models (Boko *et al.,* 2007).

Climate variability is also expected to increase, resulting in more frequent incidence of extreme events, including droughts, floods and storms mainly from tropical cyclones and wild fires brought about by increased temperatures and drier environments. The implications of these changes in climate offer both challenges and opportunities to agriculture in Africa. Systems are already vulnerable, and heavily exposed to climate risk, and so those areas with predicted drying are likely to suffer greatly from droughts. However, those areas where rainfall is predicted to increase could indeed capitalize on such opportunities if farming communities adapt.

Impact on agrobiodiversity

Climatic changes, in combination with other drivers, are expected to substantially alter agricultural biodiversity. Ecosystems will change with the climate, and drylands are particularly vulnerable because small climatic changes can have serious impacts on biodiversity, and because drylands are already under stress (CBD, 2007). Crop suitability models predict that Sub-Saharan Africa and the Caribbean will be most affected in terms of reduction of suitable area for a range of crops (Lane and Jarvis, 2007). The magnitude of change can be such that existing crop varieties are no longer suitable in a particular location. This will influence overall distribution of agro ecosystems in Africa and will have a profound impact on the livelihood systems of people inhabiting them. At species level, biodiversity which is already endangered or vulnerable will face an increased extinction rate. There will also be a loss of intraspecific diversity and disappearance of marginal plant populations. This can be particularly serious for wild relatives of crops, which may contain valuable genes for plant breeding programmes for increasing heat and drought resistance or resistance to pests and diseases. Threat patterns of insects and pathogens will also likely change, increasing risks of crop failure to smallholder farmers. CBD also cites a number of other impacts on plant growth and production including: increased exposure to heat stress, leaching of nutrients in areas with more intensive rains, erosion due to strong winds, and wild fires. (CBD, 2007). There is already abundant evidence of change in patterns on insect distribution that affect both beneficial (e.g. pollinators) and harmful insects (Menéndez, 2007). However, at present, the data come largely from studies undertaken in developing countries. Of the significant changes in biological systems analysed by IPCC that may be attributable to climate change from 1970 to 2004 some 28 115 changes were recorded in Europe, but only 2 for Africa**.**

It is likely that there will need to be significant movements of crop and livestock species and varieties as production environments change. Many major crops are widely adapted to a range of environments but the specific varieties may need to change to meet new conditions. New varieties of many crops will also be needed to match new combinations of temperature, water availability and photoperiod. In contrast to annual crops and many livestock types which can be transferred and adapted to changing conditions, soils are not mobile and adaptation of soil diversity will depend on having sufficiently large population and species diversity to allow adaptation. In some cases the present 'fit' between currently adapted crops, soils and other agrobiodiversity components will be markedly altered in unpredictable ways.

How Could Management of Agro biodiversity Help Adaptation to Climate Change?

Broad efforts to help reduce climate vulnerability of production systems will be required in agriculture, forestry and agroforestry systems, including fisheries and animal husbandry. At a given location, three basic options for adapting cropping systems to climate change are at hand:

- Migration of crop varieties to fit a new climate zone
- Adaptation of varieties through selection and breeding
- Substitution of new crop species for the old ones

These options are discussed below (of course, one can also think of scenarios of shifting away from crop production to other types of production, such as intensive horticulture, or forestry-based production, or shift to non-agriculture livelihood strategies, or migration to urban areas, but these will not be discussed here).In this section the discussion is focused on crops; similar discussions could also be held for other elements of agrobiodiversity.

Migration of crop varieties to fit a new climate zone

Because of the changing temperature and rainfall climate and increased climate variability, farmers may need different varieties of particular crops, compared to the ones they presently use. These varieties, whether landraces or modern improved varieties, would currently be grown or conserved elsewhere, including in other countries. A range of mechanisms will be needed to ensure that farmers can access these varieties:

- Information on existing variation: This requires that varieties in gene banks and in-situ collections are characterized, according to descriptor lists, and that this information is organized in databases which are available to users. However, this system would only cover the formal seed system. The informal seed systems, which dominate in marginal areas and among resource-poor farmers, would need other information mechanisms. Participatory tools such as 'seed diversity fairs' or community seed banks can serve this need of information sharing.
- Improved seed systems: Both formal and informal seed systems must to take into account increased need for migration of varieties. In the formal seed systems, better links between gene banks and breeders are needed, and competence in international exchange of seeds will need strengthening. Informal seed systems might need new institutional mechanisms, because the transfer of varieties in future will need to cover longer distances. For example, long-distance exchange among farmers may be required.
- Material transfer agreements: Cross-national exchange of seeds is likely to increase, because a useful variety may currently be grown or conserved in a different country. The International Treaty on Plant Genetic Resources for Food and Agriculture (FAO 2002) makes provision for such sharing, but not all crops are covered and not all countries have signed. And even in countries which have signed, a lot of awareness raising and capacity building will be required for material transfer to become effective.

Adaptation of varieties through selection and breeding

Climate change and variability will influence plant breeders' work in several ways: New varieties need to be developed more quickly for traits such as drought and heat tolerance, shorter period from sowing to maturity, resistance to a new set of pathogens, tolerance to extreme weather events, etc. Genes with particular characteristics can be sources from the entire genepool, including from crop wild relatives. The accelerated erosion of the genepool in many species including in their wild relatives, is a serious concern, however, as genes that useful to breeding for adaptation to climate change might be lost forever. Species which are propagated clonally, such as banana, require molecular tools.

Genes valuable to breeders may currently not be accessible because genebank accessions are not characterized. Promising genes may therefore not yet be identified. Pre-breeding could enhance the value of collections by mapping and sharing information on the genepool of a species. Increased attention to farmers' traditional knowledge on biodiversity for food and agriculture is also very important, particularly in marginal areas and among resource-poor farmers. Participatory varietal selection can serve the function of identifying varieties adapted to climate variability, for example. Participatory plant breeding can help overcoming agronomic or market constrains associated with the selected landraces. It important to also recognize farmers' rights and benefit sharing arrangements in this process. Attention to farmers' seed systems will be required. The development or maintenance of a diversity of varieties, both new and traditional, with variable properties can help spread risks. Plant breeders may benefit from paying increased attention to existing traditional risk management strategies and enhancing the diversity available both in terms of numbers of varieties with a broader genetic base and in developing varieties which are multi-lines or mixtures (Cooper *et al.,* 2000).

Substitution of crop species

A third option to address changing crop suitability is to substitute new crops, which have previously not been grown in an area, for the ones farmers currently use, such as shifting from maize to sorghum and millet instead as the climate gets dryer. Such changes requires capacity and resources in the entire agriculture sector, from research to extension, from supply of agriculture inputs to farmers' agronomic practices, including pest management and post-harvest handling. The issue of resilience of production systems will be critical. This calls for a broader portfolio of crops, and an increased emphasis in the farming systems on diversity within and among species. Putting more emphasis on neglected and underutilized crops is one such opportunity. Market influences are likely to play an increasing role in all of the above scenarios. In particular, the increasing role of supermarkets will have a profound influence on what crops and varieties farmers' grow. A particular challenge is to match small-scale farmers' production systems to the modern supermarkets' demand for quality, quantity, packaging, sanitation etc. This calls for a much better integration between, and participation of, farmers, breeders and market specialists in the adaptation to climate change. Much can also be learned from farmers' current strategies for coping with climatic stress, such as continuous introduction and trial of new materials that target specific climatic stresses, or maintaining a repertoire containing a wide diversity of planting material (i.e. varieties of same plant) or a mix of different plants from which farmers select planting materials depending on their perception of the cropping season.

Learning to Adapt to Climate Change and Variability

How can better conservation and use of agrobiodiversity contribute to adaptation to climate change? What knowledge, skills and attitudes will be required? What teaching and learning strategies could develop such competencies, in a situation with a rapidly evolving knowledge base? These are questions universities and colleges need to ask as they review curricula in coming years. Because agrobiodiversity is shaped by interactions between genetic resources, the environment and people, the study of change in species and ecosystems is not enough. One also need to understand the underlying causes of change and loss in agrobiodiversity, including the various social, economic and policy processes that influence land use. Many topics required for understanding agrobiodiversity and the processes that shape it – described earlier in this paper – are already taught in various subjects, such as integrated pest management, watershed management, soil and water conservation, agroforestry, integrated natural resources management, etc. These topics have in common that they require participatory approaches, a focus on farmer's realities through relevant practical learning experiences, and a combination scientific and traditional knowledge. Such tools are available, but may need to be adapted to the study of agrobiodiversity, especially taking into account that climate change will accelerate these processes. Other topics to be taught will be specific to the conservation and use of agrobiodiversity, in the context of adaptation to climate change.

Agro biodiversity need to be understood at three levels: diversity of agro ecosystems, diversity of species and variation within species, including the ecological and socio-economic processes that connect these levels. Especially, the study of population patterns and intraspecific genetic variation needs strengthening. Understanding the functions of fragmented landscapes and how they change in space and time will be increasingly important. Pollinator diversity, central to functioning landscapes, needs particular attention. The CBD therefore launched, in 2002 a cross-cutting initiative on the conservation and sustainable use of pollinators (CBD, 2008). Much progress has been made in recent years in the study of multi-functional landscape mosaics by initiatives such as Alternatives to Slash-And-Burn (ASB) , or Rewarding Upland Poor for Environmental Services (RUPES). Again, learning resources available from these initiatives can be re-used and adapted. Biodiversity is essential for food security and nutrition and offers key options for sustainable livelihoods (CBD, 2008b). Food and nutritional security can be enhanced by making better use of a plant, tree and animal diversity, through participatory breeding of local varieties, or a commercialization of neglected and underutilized crops. However, there is a lack of nutrient information for many food species. Plant breeding is already taught in most programmes, but in addition to 'classic' plant breeding, courses also need to cover alternative approaches to plant breeding which integrate: a perspective of agrobiodiversity and agro-ecosystem maintenance and use. This is important because breeding to meet low input and sustainable approaches may involve additional or different concerns from those that have been reflected in plant breeding curricula to date. Examples of topics which needs enhancement include participatory varietal selection and participatory plant breeding, base broadening and the development of multi-lines and variety mixtures as deliberate breeding strategies. Knowledge of both formal and informal seed systems will also be important.

Plant breeding can also enhance nutrition. Harvest Plus, a broad research programme, is aiming at reducing micronutrient malnutrition, or 'hidden hunger' by breeding staple food crops that are rich in micronutrients (Harvest Plus, 2007). Many education programmes need to strengthen their interface between agriculture and health and nutrition.

Soil biodiversity provides very important environmental services through their role in the regulation of the water and nutrient cycles, nitrogen fixation, etc. Soil biodiversity is particularly sensitive to climate change, because it moves slowly. Students will also need to know the rapidly changing international policy framework of relevance to agrobiodiversity, especially the three conventions on biodiversity, climate change and desertification, and their relevant programmes on agrobiodiversity. It is also critical to know about the International Treaty on Plant Genetic Resources for Food and Agriculture, adopted in 2001 and entered into force in 2004. The Treaty has contributed to the creation of a multi-lateral system of access and benefit sharing of the 64 most important crops and fodders species (FAO 2002). This has far-reaching implications for the sharing of germplasm among countries, for the global public good. As climate change will lead to increased movement of germplasm, such knowledge is essential in many agriculture professions.

Capacity is also urgent needed in Africa on interpreting and using outputs of climate models. Also urgent is capacity building on the issue of delivery of climate information to the agricultural sector. Agriculture extension will need to work with farmers on the substitution of species and varieties adapted to the emerging climate. Farmers need information on new pests and diseases, and how to prepare for long-term effects (e.g. gradually increasing temperature) and short-term effects (e.g. increasing frequency of extreme weather events) of climate change.

Conclusions

Adapting learning on agriculture to climate change is no easy task and many of the challenges involves is connected with a paradigm shift from a 'blueprint approach' to agriculture development, towards a 'learning-process approach'. Universities should review curricula to include agrobiodiversity dimensions in teaching of climate change. Innovative, experiential teaching methods and active student participation would help institutionalize holistic and action-oriented learning with a strong element of 'soft skills'. Education must be research-driven to incorporate a rapidly growing knowledge base on agrobiodiversity and climate change. Research capacity will need strengthening, including dramatically increasing MSc and PhD theses opportunities, for example on neglected and underutilized species, or on farmers' risk mitigation strategies. A particular challenge is how to teach in a situation with uncertainty and lack of data. Teachers will not have the right answers, and so they will need to use innovative learner-oriented methods, rather than teacher-centered ones. They need to facilitate learning, rather than lecture. There is need to develop and use more interactive methods, questioning and discussion. There is need to develop skills of seeking out new information which can support 'life-long learning', for example via web-based tools such as the Global Platform on Agro biodiversity Research (PAR), endorsed by the CBD in 2004 http://www.agrobiodiversityplatform.org. PAR will become a valuable repository for learning resources and curriculum development tools on agrobiodiversity, and a vehicle for networking and knowledge sharing. Bioversity International is also currently developing a set of Learning Cases on agrobiodiversity, designed to stimulate class room discussion on key topics. These will gradually become available on-line to enhance problem-based learning on agrobiodiversity and climate change.

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12. Agroforests, Biodiversity and Farmers' Strategies in the Sudano-Guinean Savannah Of Cameroon.

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Abstract

Home gardens in the Sudano-Guinean savannah are multipurpose agroforestry systems that combine environmental and socio-economical sustainability. The objective of the present work was to evaluate the structure and functioning of homegardens in the Niza'a tribe in a bid to understand the strategies developed by the farmers in managing biodiversity in this traditional system. Participative and reiterative interviews in addition to field observations were used to investigate 90 homegardens. The results showed that home gardens are young (less than 30 years) and their areas are small (less than 1 ha). A total of 128 species were found including 122 plant and 6 animal species. The most important medicinal plant species collected by farmers was found in this system. The fruit-producing trees such as *Mangifera indica, Persea Americana* and *Citrus* spp. occupied the highest portion of tree population on which the Niza'a people depend for their livelihood. On the basis of a cluster analysis of tree/density and subsequent further grouping using farmer and homegarden ages, size, number of animals, crop yields as additional characteristics, 11 homegarden types were identified. Types 10 (50%) and 11 (15.56%) were the most represented in the region. Their average yields were 1.52 and 2.1t/annum respectively. Significant correlations were observed between the fruit yield and the total number of trees (r = 0.37; p = 0.05) in the system on the one hand and the tuber production and the total number of animals (r= 0.26; p = 0.05) raised in the agroforest on the other. Litter and animal wastes played an important role in the fertility of the soil. The existing numerous and varied farmers' strategies should be improved for stakeholders to gain more benefits from the management of this biodiversity.

Key words: Agroforests, Biodiversity, Sustainability, *Niza'a,* Wellbeing.

Introduction

The increasing population and environmental degradation have resulted to food insecurity in the Sudano-Guinean savannah of Cameroon. Agroforestry systems have a huge potential in alleviating this food situation (De Foresta and Michon, 1996; Thaman, 1990). Homegardens in the Sudano-Guinean savannahs of Cameroon are among the old agroforestry systems practised for many centuries by the local populations to solve shortages. They are confined to the area immediately surrounding the home and composed of a number of plant components of different status forming several layers of canopy (Fernandes *et al*., 1984; Michon *et al*., 1986; Nair, 2002). The systems are complex and practised by the Niza'a people with rich cultural heritage. The indigenous knowledge of the systems is confined to each ethnolinguistic group found in the zone where communication is not easy. However with increasing population and environmental degradation there is a surge of food insecurity. Agroforestry systems including home gardens have a huge potential in alleviating the food situation in the area (De Foresta and Michon, 1996; Thaman, 1990. Because of their close association with the natural surroundings, Niza'a farmers have developed sophisticated knowledge systems. Like in Amazonia (Pritchard and Nair, 2006) and India (Peyre *et al*., 1994), the Niza'a people possess agricultural systems based on a great variety of cultivated plants, including fruit trees and various food storage technologies (Mapongmetsem, 2005a). To date, little scientific attention has been given to the promotion of these traditional systems that are of significant importance to local farmers. To meet household and conservation needs as recommended by Duguma and Mallet (1995), Leakey (1995) and Mapongmetsem (2005a), such efforts would need to be based on a deep understanding of the current composition and dynamics of these homegardens.

The overall objective of this study is therefore to analyse the structure and functioning of this traditional system with a view of understanding the strategies developed by farmers in managing its biodiversity. Specific objectives are (1) To characterize the tree diversity within and among the homegardens among Nizas group (2) to evaluate the biological richness of the system and strategies used by the farmers to manage the biodiversity in the system (3) and evaluate the production of this traditional system.

We do hope that this information will contribute to formulation of strategies aiming at improving this traditional system in the area.

Materials and Methods

Study site

The study was carried out in the Galim-Tignere subdivision of the Faro and Deo Division. The villages investigated were Sabangari, Mayo dankali, Mayo Sang-Naré, Wogoumdou, Ngouri, Toupouri, Djaligo, Mboudoua and Garbayain the Adamawa highlands (LN : 07, 236 ^{o}; LE :13,3472°). The average altitude is 1250m above sea level (ASL). The climate is characterized by a rainy season (April-October) and a dry season (November – March). The mean annual precipitation is 1479 mm and the mean monthly temperature is 22˚C (Yonkeu, 1993). Natural vegetation varies from shrubby to woody savannah dominated by Daniellia *oliveri* Hurth and Dals and *Lophira Lanceolata* Van Tiegle ex Keay (Letouzey, 1968). It is highly degraded by anthropic activities such as pasture, agriculture and bush fires (Mapongmetsem *et al.*, 2000a). The human environment is composed of numerous ethnolinguistic groups among which Foulbé, Mboum, Péré, Koutine, Haoussa, Niza'a (Yem-yem) and Dii (Dourou) are the most dominant (MINEF, 1994). For the present study, the Niza'a was selected because of their powerful culture which they celebrate every year. The main population activities in the area are animal husbandry and beekeeping.

Methodology

A total of 90 homegardens distributed in the above mentioned nine villages were investigated in Galim-Tignere subdivision. In each village, 10 farmers selected randomly were interviewed during the rainy season. The research approach followed is that of the Agriculture Research for Development (RAD). Reiterative and participatory ethnobotanical interviews were undertaken using a questionnaire composed of various types of questions: opened, closed and oriented. The main parameters of the questionnaire were: main species managed as crops in the system and their use, age and area of homegardens, yield and constraints. In homegardens, a detailed survey of the composition and management practises was made. The survey consisted of an inventory of trees and shrubs species and a count of all individuals per species. The presence of herbs was recorded for herbs. In addition, field observations were done and plant specimen were collected and identified *in situ* or taken to the National Herbarium in Yaounde for species determination.

Data processing

Principal component analyses and hierarchical cluster analysis were done through Stabox 6 and R4 programmes.

The 90 homegardens were classified using a hierarchical cluster analysis was applied using tree/shrub species density (number of individual per species per unit area) as main variable. In the cluster analysis, chi-square as distance or similarity measure and between group average linkage methods was used. Analysis in principal components was also used to describe relations between the variables. The analysis of the floristic composition of the agroforests, species richness, diversity and equitability were calculated for the tree species in each of the 90 agroforests using information from the sample plots. Diversity was calculated using the Shannon index and the Simpson index. The two indices together give a good description of the alpha (within site) diversity of the agroforests (Sonwa *et al*., 2007).

Results and Discussion

In the Niza'a tribe, homegarden is locally known as ''goumsi'' which means place where wastes are kept or simply, fruit trees around the house.

Socioeconomic characteristics of the Niza'a farmers

The total sample of the farmers is composed of 38.6 % farmers between 30 and 40 years old and 38.4 % from 46 to 60 years, two (2), seven (7), ten (10) and eleven (11) with all age groups found in the area. However there was consistent variation among villages for example Tagouri distinguishes itself by the absence of farmers less than 30 years old. This can be justified by the massive departure of young peoples to town to look for jobs. It was observed that in the villages, only old people stayed to look after the family. In Mayo sang-Nare, Wogomdou and Garbaya there were no farmers aged over 60 years (Table 12.1).

For the matrimonial status 51.7 % of the farmers are monogamous against 45.6 % of polygamous cases. Among, this monogamous trend in is respected in Mboudoua, Djaligo, Ngouri, Mayo dankali and Sabongari and polygamy is more common in Wogomdou (56.3 %), Mayo Sang-Naré (53.8 %), Tagouri (53.3 % and Garbaya (53.8 %). This can be attributed to the proximity of the villages to the mining centre. Many of the men are involved in the marketing of the ''blue stone'' or Saphire and remarkably, no bachelor has been identified among the farmers of the region. In the traditional African culture in general and Niza, in particular, bachelor life is not appreciated by the members of the society, especially the old. In Garbaya village, 7.7 % of respondents were widows.

Fifty three percent of the families had a family size, of 5 to 10 members in Mayo sang-Nare, Wogoumdou, Ngouri, Djaligo and Mboudoua. Families with more than 11 persons are associated with people who have responsibility in the village (Djaoros, Notables). Similar results are reported in East Asia (Mapongmetsem *et al*., 2000b). All the families were headed by men because, the majority of Niza'a are Muslims and women can neither inherit properties nor respond to questions without the authorisation of their husband.

Typology of the agroforests

Cluster analysis using a similarity index of 0.96 as cut-off point, classified the 90 selected home gardens the 90 selected homegardens into 11 types with different pattern (Figure 12.1). The types 10 (50%), 11 (15.56%), 7(11.11 %) and 2 (8.89%) were the most represented in the region. The types 3, 5 and 6 were less represented in the region (1.1%). They are specific agroforests. All the farmers belonging to the type 2, 4, 6, 8 and 9 do not raise animals (cattle, goats and sheep). Those of type 1 raise only sheep. Type 5 has only cattle whereas in types 7, 10 and 11, different animals are present. The cattle possession in the region becomes more and more important because of their use in soil labour and restoration. Agroforest types 7, 10 and 11 group farmers are of different ages whereas in types 3, 5 and 6, they are between 41 and 80 years old.

Table 12.1. Farmer percentage according to their age per home garden type.

Homegarden type	**Age (years)**				
	< 30	30-40	41-50	51-60	>60
T1 (n=2)	0	50	0	50	0
T2 (n= 8)	37.5	25	25	12.5	0
T3 (n=1)	0	0	0	100	0
T4 (n=4)	0	25	0	50	25
T5 (n=1)	0	0	0	100	0
T6 (n=1)	0	0	100	0	0
T7 (n=10)	20	40	20	10	10
T8 (n=2)	0	50	0	50	0
T9 (n=2)	0	50	50	0	0
T10 (n=45)	8.9	33.9	14.8	26.7	13.3
T11 (n=14)	17.1	28.6	21.4	35.7	7.1
Mean	**7.6**	**25.23**	**21.09**	**39.54**	**5.04**

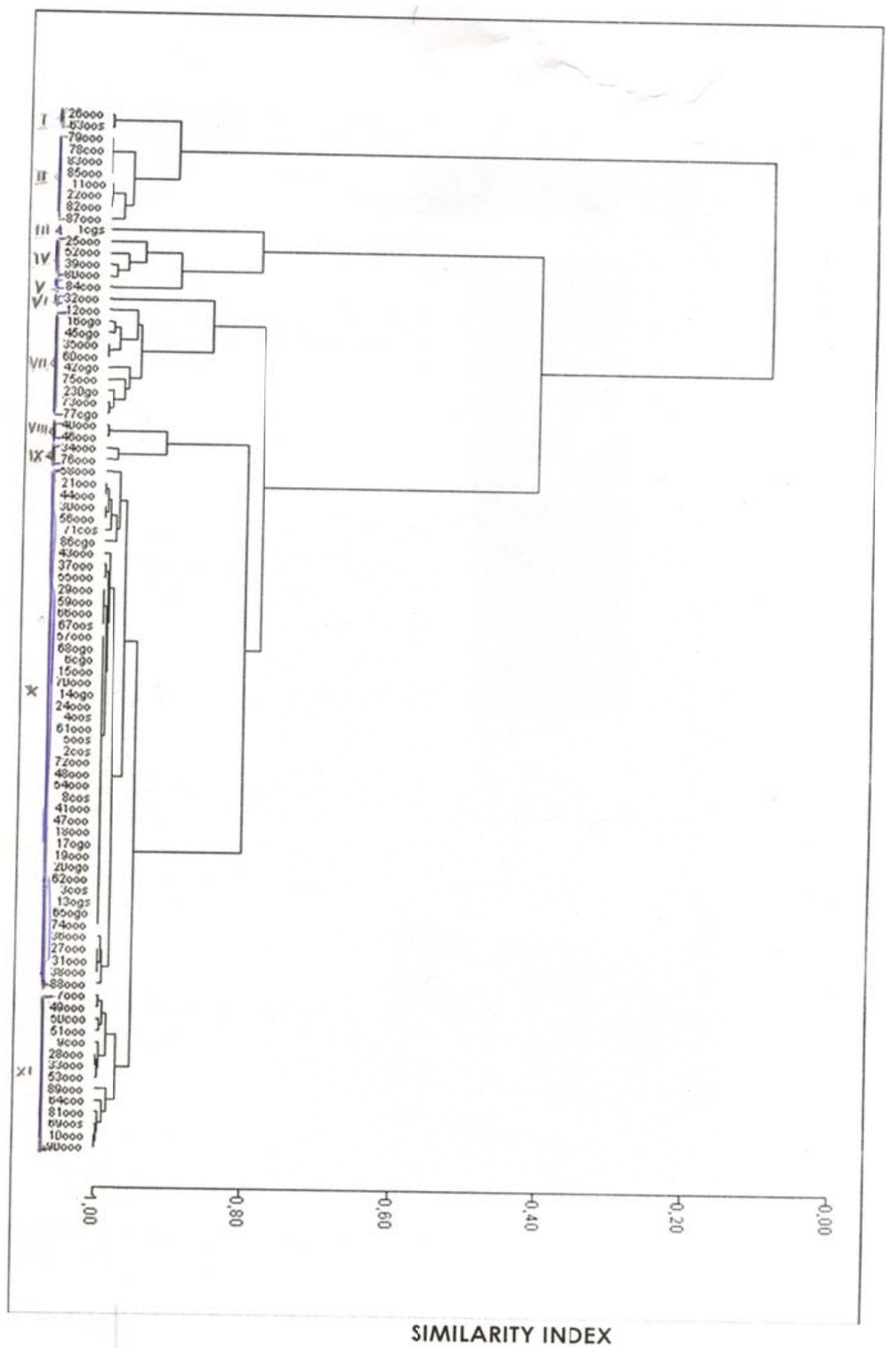

Figure 12.1. Hierarchical classification of 90 home gardens of the Sudano-Guinean savannah.

Structural characteristics of the agroforests

Homegarden age

About 67.32 % of the Niza'a homegardeners are between 11 and 40 years old suggesting that they are young. Between types, consistent disparity exists. Old homegardens (>40 years) are found in types 4, 5 and 10. On the other hand, the mobile population the recent homegardens in the Niza'a group can find explanations. The youngest homegardens (less than 10 years) are found in types 1(50 %), 2(37.5), 7 (30 %), 10 (22.2 %) and 11 (28.6 %). These results are in agreement with that of Mapongmetsem *et al.* (2002). More than 57 % of them are less than 30 years old. There is a significant positive correlation between the age of the farmer and that of the homegarden (r =0.63; p =0.05) clearly indicating that 63 % of the farmer were generally, with old homegardens. The maximum number of layers found generally in home gardens is 5 (Michon *et al.,* 1986). Five strata are effectively present in types 4, 5 and 10 which are old whereas only four of them exist in the rest.

Homegarden area

The 90 homegardens evaluated in the Niza'a ethnolinguistic group cover a total surface of 124.68 ha. There was significant positive correlation between the farmers' age and the area of the agroforest (r = 0.21; p = 0.05). This relationship suggests that the older the farmer, the larger the surface of his garden. In general, the surface of homegardens in the Niza'a is very small. About 90 % of them have less than 0.5ha. This result is in agreement with the findings in other tropical homegardens (Mapongmetsem, 2005a). Large homegardens of more than a hectare (33.3 %) are found only in the homegardens of type 10 and the average (0.51-1 ha) in 2 (50 %) (Table 12.2).

Species richness, diversity and frequency

A total of 128 species were found including 122 plant and 6 animal species. The average number of plant species per agroforest type was 17. The number of trees vary significantly (0.000 < 0.001) among the homegarden types. The most diversified homegardens are types 4 (23 species), 5 (32 species) and 7 (18 species) whereas the poorest is type 6 with 9 species. In general, an increase in richness of homegardens appeared to correspond to a decrease in Shannon's and Simpson's index (Table 12.3).

These results are in disagreement with the findings of Peyre *et al*. (2006) in India. These figures are lower than those obtained in cocoa agroforests in the humid forest zone of Southern Cameroon (Sonwa *et al*., 2007) and in Indonesia (Kanyon, 1990) and higher than those obtained in Amazonia (Smith, 1996). The Shannon index (more than 2) in agroforest type 1, 2, 3, 6, 9 and 10 was similar to the findings of Kaya *et al*. (2002) in Central Maluku in Indonesia. Different types of plant species are found in the Niza'a home gardens; fruit trees, crops and wild trees.

Fruit trees constitute the essential of species found in the Niza'a system. All the farmers are home consumption oriented. Similar results are reported in the region (Mapongmetsem *et al*., 2002). *Mangifera indica*, *Persea americana*, *Carica papaya*, *Citrus* spp., *Musa* spp., *Adansonia digitata*, *Tamarindus indica*, *Ziziphus mauritiana*, *Parkia biglobosa*, *Commiphora kerstingii*, *Ficus thonningii*, *Anacardium occidentale*, *Psidium guajava* are the species that were commonly found in Niza'a s' agroforests across the study region (Table 12.4).

Table 12.2. Percentage of farmers according the Age and area of homegardens

Homegarden Type	Age (years)						Area (ha)		
	<10	11-20	21-30	31-40	>40	<0.25	0.25-0.5	0.51-1	>1
T1 (n=2)	50	0	0	50	0	0	100	0	0
T2 (n= 8)	37.5	37.5	12.5	12.5	0	75	25	0	0
T3 (n=1)	0	0	0	100	0	100	0	0	0
T4 (n=4)	0	50	25	0	25	75	25	0	0
T5 (n=1)	0	0	0	0	100	100	0	0	0
T6 (n=1)	0	0	100	0	0	100	0	0	0
T7 (n=10)	30	40	20	10	0	90	10	0	0
T8 (n=2)	0	0	50	50	0	50	0	50	0
T9 (n=2)	0	100	0	0	0	100	0	0	0
T10 (n=45)	22.2	35.6	22.2	11.9	8.9	13.5	28.9	24.4	33.3
T11 (n=14)	28.6	14.3	42.8	14.3	0	50	50	0	0
Mean	12.27	22.19	22.52	22.61	12.09	68.5	21.72	6.8	3.0

Table 12.3. Average species richness and diversity of trees in Niza'a homegardens in the Sudano-Guinean savannah of Cameroon.

Agroforest type	**Species abundance**	**Species richness**	**Shannon index**	**Simpson index**
1 (n= 2)	20	16.5	2.36	0.89
2 (n= 8)	15	14	2.02	0.86
3 (n=1)	23	15	2.09	0.86
4 (n= 4)	24	23	1.8	0.79
5 (n=1)	49	32	1.4	0.72
6 (n= 1)	16	9	2.01	0.84
7 (n= 10)	22	18	1.6	0.76
8 (n=2)	16	11	1.9	0.84
9 (n=2)	15	14.5	2.2	0.89
10 (n=45)	20	16	2.3	0.89
11 (n=14)	19	16	1.6	0.78
P-Value	0.034 < 0.05	0.000 < 0.001	0.000<0.001	0.046<0.05

n= number of homegardens

Table 12.4. The 10 most frequent tree species with a diameter at breast height ≥2.5 cm in the Niza'a agroforests , and percent of inventoried homegardens where they were present.

Species	**Family**	**Main Uses**	**Mean Frequency (%)**
Anacardium occidentale	Anacardiaceaee	Exotic, edible fruits, medicinal, wood	70
Adansonia digitata	Bombacaceae	Indigenous, edible fruits and leaves, medicines	100
Balanites aegyptiaca	Balanitaceae	Indigenous, edible fruits and leaves, medicine,	50
Borassus aethiopum	Arecaceae	Indigenous, edible fruits, handicraft	70
Carica papaya	Caricaceae	Exotics, edible fruits, medicinal	70
Citrus spp.	Rutaceae	Exotics, edible fruits	100
Commiphora kerstingii	Burseraceae	Indigenous, live fences, medicine	70
Ficus thonningii	Moraceae	Indigenous, live fence, medicines, edible fruits	70
Mangifera indica	Anacardiaceae	Exotics, edible fruits, medicines, bee forage	100
Musa spp.	Musaceae	Exotic and edible, medicines	100
Parkia biglobosa	Mimosaceae	Indigenous and use as spice, medicines	70
Persea americana	Lauraceae	Exotic and edible fruits, medicines	100
Phoenix dactylifera	Arecaceae	Exotics, edible fruits	50
Psidium guajava	Myrtaceae	Exotic and edible fruits, medicines	70
Syzygium guineense	Myrtaceae	Indigenous and edible fruits	50
Tamarindus indica	Mimosaceae	Indigenous, edible fruits, medicines	100
Vitex doniana	Verbenaceae	Indigenous and edible fruits	50
Vitellaria paradoxa	Sapotaceae	Indigenous and edible fruits and oil, medicines	50

However, the proportion of these species differed widely among the agroforest types. *Mangifera indica*, *Persea americana*, *Citrus* spp., *Musa* spp., *Tamarindus indica and Adansonia digitata* occurred in 100 % whereas *Anacardium occidentale*, *Borassus aethiopum*, *Parkia biglobosa*, *Psidium guajava*, *Ficus thonningii*, *Commiphora kerstingii*, *Ziziphus mauritiana* occurred in at least 70 % of the agroforests. The most abundant tree species accounted for 50 % of all trees inventoried in the agroforests. The Niza'a farmers manage various plant species found in their system (crops, leguminous species, vegetables, fruit trees, spices, medicinal and ornamental plants) to feed and treat themselves as well as their environment. *Functional characteristics of the agroforests*

The high species diversity mentioned above ensures a steady supply of nearly all kinds of goods for daily needs.

Food production

The selection of principal crop species and subsequent overall species diversity is apparently influenced by the individual farmer's choice and site condition. The following food items are found in the Niza'a homegardens: cereals, tubers, legumes, vegetables and fruits. The total yield in the Niza'a homegarden of the sudano-guinean savannah is 76.3 tonnes/annum made up of 2.1 tonnes of cereals, 52.8 tons of legumes, 3.7 tons of tubers and 17.7 tonnes of fruits. The most important production of the Niza'a agroforest is composed of legumes followed by the fruits. This result is in disagreement with the findings of Mapongmetsem *et al*. (2006) in the Foulbe where cereals were the essential of the production after fruits. Between the agroforest types, consistent disparity exists. Types 1, 2, 5 and 8 are the most productive homegardens in the Niza'a (Figure 12.2).

All the farmers belonging to the agroforest of type 6 did not produce cereals. Almost the total production in home gardens is consumed. However the excess of products could be sold in order to buy products which are not produced in the homegarden.

The incomes generated from the commercialization of these products help to buy soap, meat, salt, oil, clothes, animals and pay school fees of the children. Mapongmetsem (2006) reported similar results in the region. The management of the home gardens vary according to the socio-economic strategy of the head of the family. Fruits are the most important products sold directly on the field, along the road or in the local and / or regional markets. The fruit production obtained in the Niza'a homegarden is low compared to the finding in other regions of the Sudano-guinean savannah (Mapongmetsem *et al*., 2002). Significant correlations were observed between the fruit yield and the total number of trees ($r = 0.37$; $p = 0.05$) in the system on the one hand and the tuber production and the total number of animals ($r = 0.26$; $p = 0.05$) raised in the agroforest on the other. The richness of species planted in the homegardens ensures a year-round supply of fresh fruits and vegetables. Authors who studied plant diversity in these systems found that the timing of establishment of a garden and the management intensity has a major impact on the stand structure, species composition and yield (Smith, 1996; Sonwa *et al*., 2007).

Management and farmer strategies

To manage local biodiversity, farmers in the Niza'a developed different strategies according to the objectives of the head of family. To improve soil fertility in the homegardens, the common techniques used by all the farmers of the region, is to clean the yards, kitchen and spray dusts in the field. This practise improves significantly the soil fertility in these agroforests. Cattle dung is also used as manure to fertilize soils. After harvesting food crops, animals are conserved in the field. For farmers who are not in possession of cattle, they negotiate with herders during the dry season. In case of accords, herders bring animals and keep them in the field for two to four weeks. According to the Niza'a farmers, plots which receive cow manure as fertilizer may conserve their fertility for about five years.

To prevent goats and sheep from destroying and eating crops, farmers spray dung in the field. The dung emits a pungent smell during decomposition that repels animals. To avoid degradation of food stored in granaries after harvesting, they use aromatic local plants such as *Hyptis spicigera*, *Plectranthus glandulosus* , *Annona senegalensis*, *Lippia rugosa, Laggera pterodonta and Echinops giganteus* (Ngamo *et al*., 2007). Before sowing seeds of *Arachis hypogea*, *Vigna* *unguiculata* and *Zea mays,* some farmers enrobe them with the powder of *Psorospermum febrifugum.* This practice prevents birds, termites and rodents from destroying them. Litter from different tree species existing in the traditional system decompose and contribute to continuously improving the soil fertility. Species like *Vitex doniana*, *Vitex madiensis*, *Parkia biglobosa* and *Ximenia americana* which are very often protected in the field are sources of N, P, Mg, phenols, NDF fibres and K (Mapongmetsem, 2005b ; Mapongmetsem *et al*., 2005b).

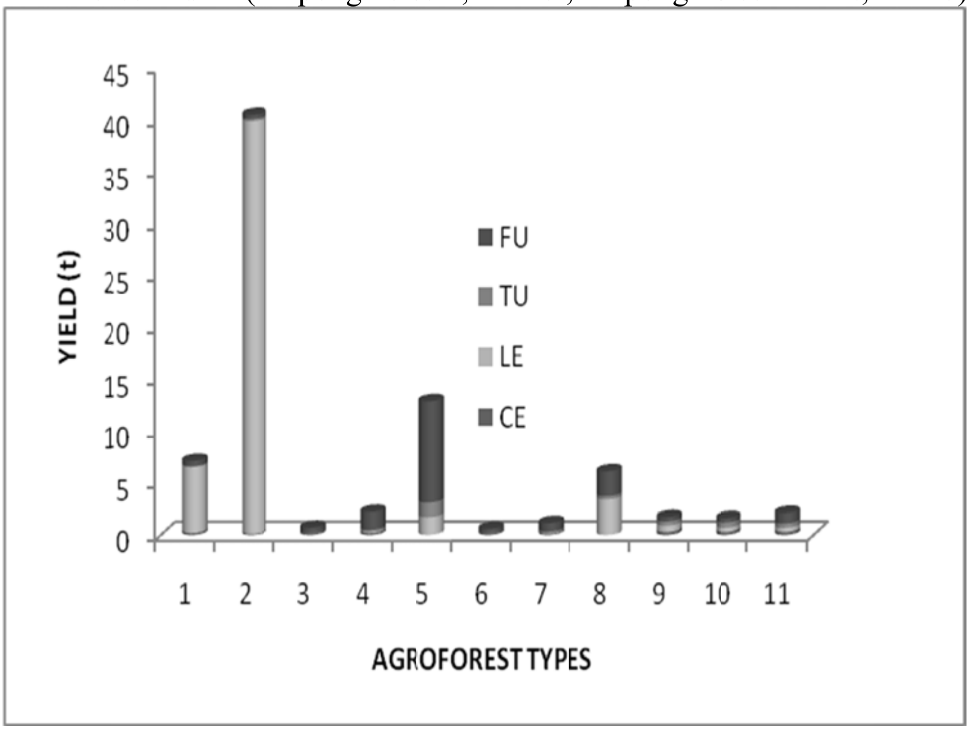

Figure 12.2. Food production in the Niza'a homegardens of the Sudano-guinean savannah of Cameroon. Food items: cereals (CE), legumes (LE), tubers (TU) and fruits (FU).

In addition to these strategies developed by the Niza'a farmers to improve their living standard, they also develop phytopratices to circumvent some constraints in arboriculture. To bring species such as *Mangifera indica and Persea americana* to flower precociously, they scarify the bark of these trees. Some of them claim that this practise is also used to fight fungus which attack the leaves and fruits of these trees. Others bury fresh horns of cattle at the bottom of the fruit trees in order to prevent them from being destroyed by termites. Other farmers put snail shells on branches to attain the same objectives. Similar practices are reported in East Asia (Mapongmetsem *et al*., 2000b). These interactions in addition to socio-economic objectives can induce changes on the functioning of this traditional system in the Sudano-Guinean savannah.

However, the Niza'a farmers are complaining of the changing climates, resulting in the shortened raining season with scarce precipitations affecting the food production in their region.

Conclusion

The Niza'a populations manage 11 types of homegardens in the Adamawa highlands. These homegarden types differ significantly in their functional and structural characteristics. The essential of the Niza'a production is composed of legumes. This study illustrates the multiple uses of native biodiversity in the Niza'a agroforests of the sudano-guinean savannah of Cameroon. Many potentially valuable non timber forest products from the local savannah flora that can grow well around the houses are found. All the farmer collections are found in the agroforests. The multiple uses attest the on-going importance of these resources to local communities, for subsistence as part of their cultural heritage. However, with increasing market access, land use intensity and urbanisation, native tree species are increasingly replaced with common and often exotic crops such as banana, citrus, mango, cashew and avocado. Choice of species tends to be edible and medicinal oriented. Homegardens contain a mixture of exotic and native plants. Of the 122 plants found in the homegardens, 48% are indigenous. Thus the Niza'a agroforests may serve as an example for the suggestion of Janzen (1998) cit. Kaya *et al*. (2002), that only a 'gardenification of the tropics is capable of preserving large lumps of wild biodiversity''. Well exploited, agroforests can constitute a means to fight against poverty.

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13. Vegetation Physiognomy and Species Composition as Tools for Land Use Planning and Sustainable Land Management in Semi-Arid Areas

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Abstract

In a vegetation - land use study carried out in nine selected sites from semi-arid parts of Zimbabwe, a multivariate technique called Canonical Correspondence Analysis (CCA) was used the purpose of which was to explore vegetation land use relationships and relate physiognomy and species composition to land potential for agriculture and sustainable land management. The results revealed strong environmental gradients and clear vegetation physiognomy patterns and species along the landscape. These vegetation physiognomy differences and land qualities that were used to separate land types from uplands to lowlands together with their potential for agriculture and sustainable land management were associated with sodicity, soil moisture, soil erosion and drainage status of the soil. It was concluded that vegetation is a promising indicator for land use potential as well as land management problems in semi-arid areas.

Key words: Canonical Correspondence Analysis (CCA), Vegetation physiognomy, land capability.

Introduction

Structural similarities among vegetation types on granite in semi-arid areas of Zimbabwe have been observed (Campbell *et al.,* 1988; Timberlake *et al*., 1993). There is a preponderance of certain plants in semi-arid flora that are rare or restricted in other types of ecosystems. Ecological research has already established that plant species would be naturally clumped in a few physiognomic types or categories each representing a convergence of strategies to cope with the environment. Using this fact, the aim of this research was to assess vegetation physiognomy patterns and species available in some selected areas in semi-arid parts of the country with granitic soils, in order to explore variance in woody vegetation abundance in these areas, identify and describe ecosystems and relate these to land use potential, planning and management in semi-arid areas of Zimbabwe.

Materials and Methods

Four study areas with granitic soils and undisturbed vegetation were selected from semi-arid parts of Masvingo and Mashonaland East Provinces of Zimbabwe (Table 13.1).

These study areas experience a sub-tropical climate with distinct summer and winter seasons. Soil types are moderately shallow to moderately deep, coarse textured Siallitic (4G), Fersiallitic (5G) and Sodic (8N) soils (Thompson, 1965). Savannah is the most dominant vegetation type (Wild and Barbosa, 1968). Vegetation physiognomy and species composition are largely determined by rainfall pattern and soil type (Anderson *et. al*., 1993). From these areas, a total of 81 woody plant species were identified and named using nomenclature developed by Biegel and Mavi (1972) in 41 plots found along 9 catenae. Homogeneous and natural woody vegetation communities were identified along the catenae and classified using the system developed by Pratt *et al*., (1966). Soil sampling for laboratory analyses was done by horizons along the catenae, according to observed patterns of vegetation and soils. Laboratory soil analyses were done using standard techniques normally used by the Department of Research and Extension (AREX) in the Ministry of Agriculture in Zimbabwe. Ordination analyses were done using Canonical Correspondence Analysis (CCA) technique with the aid of a computer program called CANOCO (Ter Braak, 1987).

Table 13.1. Study areas and the selected 9 catenae in Mushandike Wildlife Sanctuary, Makoholi, Soti Source Resettlement (Masvingo Province) and Wedza (Mashonaland East Province).

Name of Catena	**Catena symbol**	**Map Reference**	**Grid reference**	**Symbols for Vegetation plots/sites / soil profiles**
Mutsungwe	MU	Mushandike Dam, 1:50 000, 2030 B1	TN 482758	MU1 - MU6
Mushandike River	MR	Mushandike Dam, 1:50 000, 2030 B1	TN 497763	MR1 - MR4
Airstrip North (a)	ANa	Mushandike Dam, 1:50 000, 2030 B1	TN 486767	ANa1 - ANa4
Airstrip North (b)	ANb	Mushandike Dam, 1:50 000, 2030 B1	TN 491769	ANb1 - ANb4
Navik Bay	NB	Mushandike Dam, 1:50 000, 2030 B1	TN 542722	NB1 - NB5
Up Navik Bay	UN	Mushandike Dam, 1:50 000, 2030 B1	TN 548733	UN1 - UN4
Chikungurugwi	CH	Makoholi, 1:50 000, 1930 D4	TP 685066	CH1 - CH6
Agyle	AG	Soti Source, 1:50 000, 1931 A3	TP 958484	AG1 - AG4
Maruta	MA	Wedza, 1:50 000, 1831 D1	UQ 538382	MA1 - MA4

Notes: Vegetation plots or sites and/or soil profiles have been numbered from the bottom to the top of the catenae. For example: 1 = Lowest catena position, 6 = Highest catena position. Symbols e.g. MR1: CH4; AG2 etc appear in the ordination graphs in Figures 13.1 and 13.2.

Results

Table 13.2 shows an explanatory key to the abbreviations used for the environmental variables while Table 13.3 shows a summary of the weighted means, standard deviations and inflation factors for ten environmental variables used for the ordination analysis.

Clusters were delineated by eye from the CCA ordination diagram (Figure 13.1) of species density data from all study areas constrained by ten environmental variables shown in Table 13.4. Vegetation physiognomic description in sites follows the system developed by Pratt *et al.* (1966). For the soil type column equivalent land classes according to the land capability classification system (AGRITEX, 2001) is provided.

The results for the analysis of eigenvalues (Table 13.5) indicate that 67 % of the variation in vegetation species data along the catenae can be explained by the changes along axis 1 which represents the main environmental gradients of available soil moisture, drainage, soil pH, sodicity and erosion (Figure 13.1).

Table 13.2: Key Abbreviations used for environmental variable in the CCA ordination analysis

Abbreviation used	**Name of environmental variable**
%clayA	Percentage of clay in A horizon
%clayB	Percentage of clay in the B horizon
PHA	Soil pH in the A horizon
PHB	Soil pH in the B horizon
AWCA	Available water capacity in the A horizon
AWCB	Available water capacity in the B horizon
Ca.MgA	Calcium to magnesium ratio in the A horizon
Ca.MgB	Calcium to magnesium ratio in the B horizon
CECA	Cation exchange capacity in the A horizon
CECB	Cation exchange capacity in the B horizon
ESPA	Exchangeable sodium percentage in the A horizon
ESPB	Exchangeable sodium percentage in the B horizon
Se	Soil erosion hazard
Dr	Drainage status of soil

Table 13.3: Weighted means (n= 41), standard deviations and inflation factors for 10 environmental variables used in the CCA ordination.

Environmental variable	**Mean (weighted)**	**Standard deviation**	**Coefficient of variation %**	**Inflation factor**
%clayB	23.28	13.41	58	4.42
PHA	5.07	0.57	11	2.92
PHB	6.06	1.66	27	5.63
Ca:MgB	0.68	0.38	57	1.83
CECB	9.97	7.17	72	10.45
ESPB	12.16	14.23	117	2.37
AWCA	22.56	4.08	18	1.74
AWCB	20.40	3.86	19	1.35
Se	0.57	0.49	86	3.85
Dr	0.35	0.48	137	3.34

Table 13.4: A summary of the CCA ordination results from species density data for the first 4 ordination axes, for 81 woody vegetation species identified from 41 sites in the selected study areas.

Ordination axes	**1**	**2**	**3**	**4**	**Total Variance**
Eigenvalues	0.67	0.24	0.21	0.16	8.38
Species–environmental correlations	0.94	0.77	0.74	0.73	–
Cumulative % variance of species data	10.50	14.10	17.40	20.00	–
Cumulative % variance of species-environmental relationships	35.90	48.6	59.7	68.6	–
Sum of unconstrained eigenvalues					6.38
Sum of canonical eigenvalues					1.86

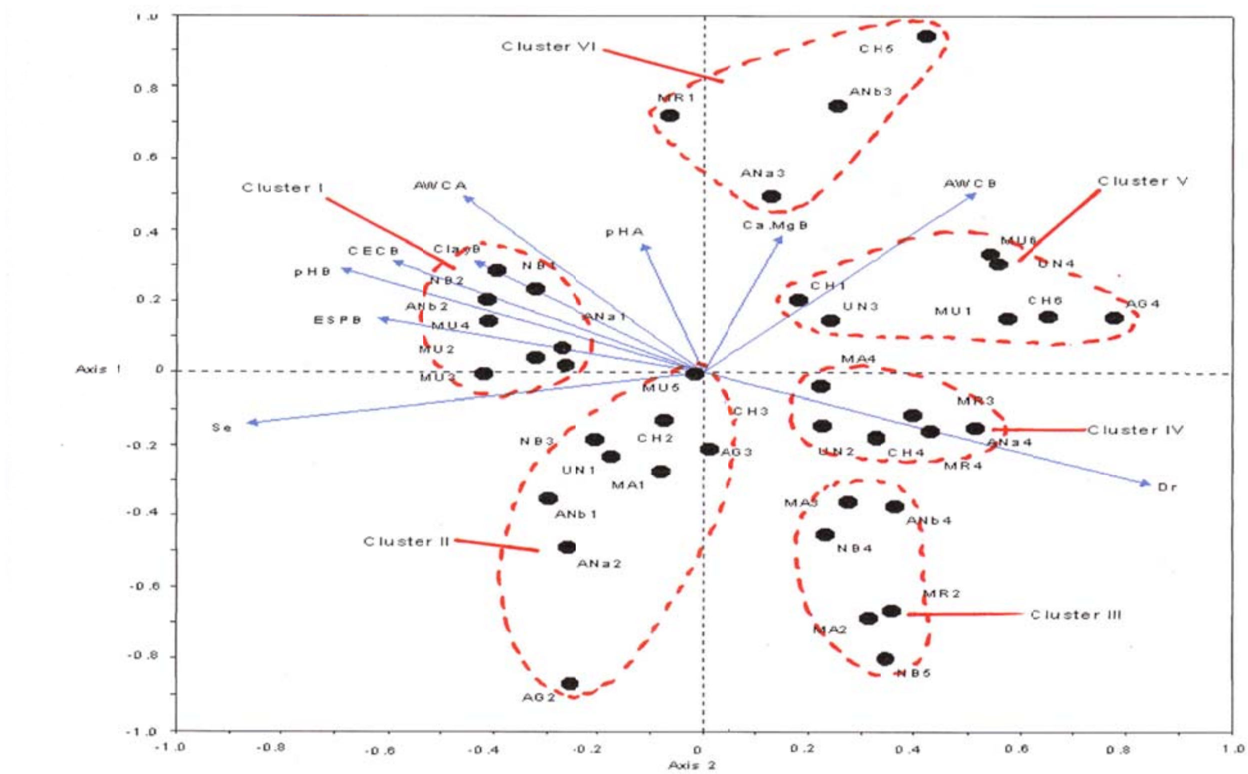

Figure 13.1. Diagram displaying clusters of vegetation sites grouped according to similar physiognomy, land qualities, soil types and equivalent land capability classes used for land use planning

Distinct patterns of vegetation sites and physiognomic types (Figure 13.1) can easily be separated by eye into six main clusters (Table 13.5) related to specific positions along the catena. For example, *Brachystegia spiciformis (11)* together with *Monotes engleri (50)* (Figure 13.1) in combination with many other dystrophic tree species occurred in the Tree Bush Savannah (TBS) vegetation physiognomic types on dry and leached Siallitic (4G) upland sandy soils equivalent to land capability arable class M III (AGRITEX, 2001) whilst Acaci*a species (1)* and *Colophospermum mopane (17)* were found on BS vegetation physiognomic types in the lower and poorly drained parts of dry sites on Fersiallitic (5G) and sodic (8N) soils of marginal potential that are equivalent to land capability arable class M IVf (AGRITEX, 2001).

Table 13.5: Vegetation physiognomic types and dominant species in sites with brief descriptions of common land qualities, soil type and equivalent land capability classes important for land use planning

Cluster Number	Sites	Dominant vegetation physiognomic type	Important land qualities and site characteristics	Soil type and equivalent Land capability class	Dominant species mnemonics
I	NB1, NB2, NB3, ANa1, ANb2 MU2, MU3, MU4	Open Bush Savannah (BS)	Dry lowlands, gently sloping, poorly drained compact soils, heavily eroded	Fersiallitic (5G) and Sodic (8NG) soils, Class M IVf	*C. mopane* *A. nilotica*
II	NB3MA1, UN1,CH2, ANb1, ANa2, AG5, MU5	Open Grasslands (GS) and Bush Savannah (BS)	Gently sloping lowlands and vleis, moderately eroded, water logged sites.	Fersiallitic (5G) with localized patches of sodic (8NG) soils Class M III ; M V	*T. sericea* *C. adenogonium* *S. guinense* *C. mopane*
III	MA2, MA3, NB4, NB5, ANb4, MR2	Open Tree Bush Savannah (TBS)	Gently undulating dry middle and upland slopes, well drained and slight erosion	Siallitic (4G) soils M II, M III and M IV	*B. spiciformis*
IV	UN1, CH4, MR4, MA4, ANa4	Dense Tree Bush Savannah (TBS)	Gently undulating dry, well drained upland sites, slight erosion	Fersiallitic (5G) and Siallitic (4G) soils Classes M I; M II; and M III	*B. spiciformis* *J. globiflora* *M. engleri*
V	CH1, UN3, MU1, MU6, UN4, CH6, AG4	Open to fairly dense Tree Bush Savannah (TBS)	Almost flat, to gently sloping, dry, well drained upland crests and interfluves	Siallitic (4G) soils Class M I; MII; M III	*B. spiciformis*
VI	MR1, ANa3, ANb3, CH5	Open, mixed Tree Bush Savannah (TBS), Bush Savannah (BS) and Grassland vleis (GS)	Gently undulating middle slopes with fluctuating water table	Fersiallitic (5G) soils hydrormophic Classes MIII; M IV; M V; M VI	*T. sericea* *P. curatellifolia* *C. molle* *E. divinorum*

Erosion, drainage and available soil moisture represent the strongest environmental gradients and appear to be most influential variables responsible for showing significant distinction between upland crests, wetlands (equivalent to land capability class MV, non-arable), dry lands and their associated vegetation physiognomy and species composition (Figures 13.1 and 13.2). To avoid congestion of species points (in Figures 13.1 and 13.2) that make interpretation difficult, a limited number of species including five most abundant ones have been selected for the purposes of interpretation. In Figure 13.2, *Colophospermum mopane* (17) found in Bush Savannah (BS) vegetation physiognomic type has higher association with soil erosion intensity than with ESPB, pHB, CECB and other soil characteristics used in the ordination analysis. Thus *C. mopane* occurs more frequently in dry lowland parts of catenae in (BS) vegetation physiognomic type where soils of marginal potential that are equivalent to land capability arable class M IVf (AGRITEX, 2001) are more eroded than any other species displayed close to it. (Figure 13.2). *Acacia nilotica (01)* was found in the same vegetation type in dry lowlands on sodic soils with heavy sub-soils (42% clay) associated with 'shrink-swell' behaviour, high ESP (25.30); high CEC (15.40 c mol c/kg) and inverted Ca/Mg ratio (0.27). It is presumably the structure and strength of the root system similar to that observed in *C. mopane (17),* which allows *Acacia nilotica (01)* to survive on these cracking soils where most woody species would suffer from repeated root shearing throughout the year and subsequent death (Timberlake *et al*., 1999). In uplands with Siallitic (4G) soils that can be put under arable classes M III or M IV according to land capability classification (AGRITEX, 2001), more *Brachystegia spiciformis (11)* species is found in combination with other species such as *Strychnos cocculoides (66)*, *Ximenia americana (75)* and *Ozoroa reticulata (53)*. In the middle slopes with perched water tables, *Parinari curatellifolia (55)* and *Acacia nilotica (01*) are two species that are found in TBS on Fersiallitic (5G) soils equivalent to non- arable, wetland class M V (AGRITEX, 2001) . Other species such as *Monotes engleri (50)*, *Diospyros mespiliformis (28)* and *Sclerocarya birrea (64)* tend to occur in a mosaic of vegetation physiognomic types and mixtures in combination with *Brachystegia boehmii (10)*, *Combretum molle (22)*, *Pterocarpus angolensis (59), Senna singueana (16)* and *Pterocarpus rotundifolius (60)* (Figure 13.2) on Fersiallitic soil (5G) that are poor to marginally arable.

Discussion

Early ecologists who described savannah landscapes in Africa focused on catenal variations existing on the landscape, describing the changes in vegetation physiognomy and species composition from uplands to lowlands (Vincent and Thomas, 1960); Scoones, 1991). Conventional knowledge in farming and land use planning, however, often does not recognize the importance of this micro variation of the landscape and its management. As a result specialisation of land use has tended to break up the integration of this landscape system by allocating various subdivisions to disciplinary specialism leading to poor linkages in the system.

In Zimbabwe, a significant contribution to this problem is presented by the land capability system, a land use planning approach that was originally developed by the former Southern Rhodesian Federal Department of Conservation and Extension (1964) along similar lines to the land capability system in the United States in the early 1960's. A clear description of the system is given by Klingebiel and Montgomery (1961) who define the objective of the classification as for assessing the degree of limitations to land use or potential land use as imposed by permanent properties. Non-permanent properties are assumed to be reducible or removable by land improvements and management. Subsequently revised by Agricultural Technical and Extension Services (AGRITEX) (1981) and adopted for Zimbabwe, the land capability system now forms the basis for land use planning. Land is thus graded from best to worst with class I to IV as arable and classes V to VIII non arable. Despite its simplicity and cheapness, this approach to land use planning however has failed to recognize the importance of landscape dynamics as it eliminates from the consideration of some of the key components of the total farming system. As a result, the system has been unacceptable to many communal farmers because of some incompatibilities to and inconsistencies with existing farming systems.

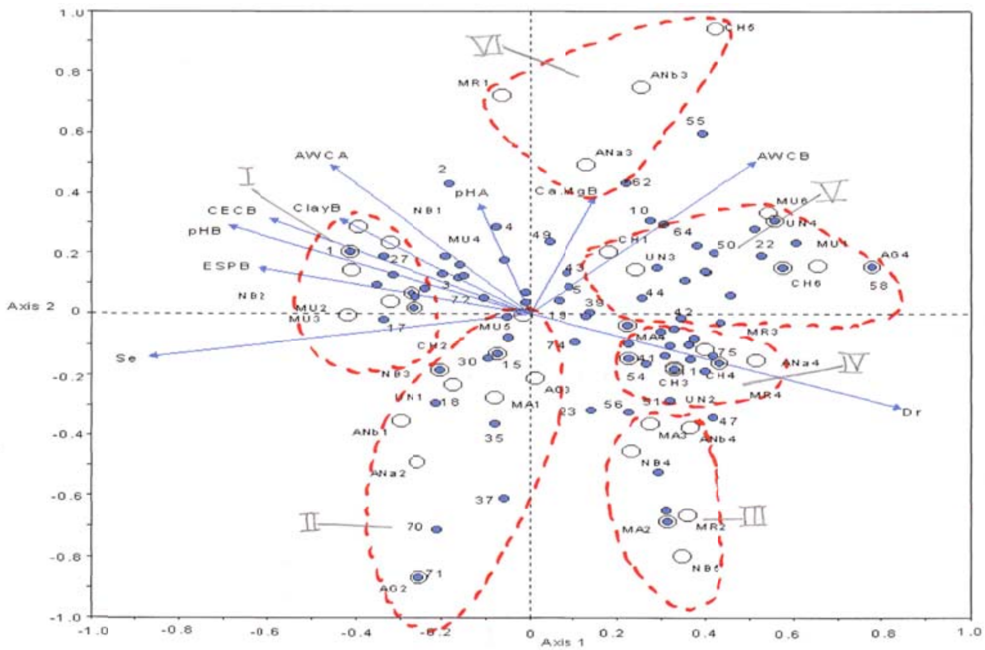

Figure 13.2. Clusters of vegetation sites grouped according to similar physiognomy and species composition, land qualities, soil types and equivalent land capability classes used for land use planning

Over the years, observations made by environmentalists including agricultural extension experts from AGRITEX in Zimbabwe do support the view that on granite in semi-arid areas, vegetation physiognomic zones occur across catenae in response to landscape micro variations, which are also related to those (variations) in soil fertility, soil moisture availability, drainage status of the and soil erosion intensity (Zhou, 2004). It would appear that the contrast therefore created between uplands and lowlands and the related vegetation physiognomy types and species composition along catenae on granite is a microcosm of a pattern that is very common in most parts of semi-arid areas found in Zimbabwe (Anderson *et al*., 1993).

For arable land use planning purposes, therefore, the well-drained uplands on granite would be most suitable for cropping with good fertilizer management coupled with appropriate crop and land rotations. Excessive clearing of natural vegetation and continuous cropping would expose the loose sandy top soils to erosion. For livestock production, the same areas (uplands) would be most suitable for rotational grazing management systems that reduces overgrazing and land degradation. As most wetlands or vleis are associated with high water levels during summer these ecosystems could be utilised sustainably in winter for cropping with appropriate water management and conservation practices as well as for winter grazing. Through application of indigenous knowledge, farmers in Zimbabwe have generally adapted to exploiting both temporal and spatial variability by promoting more rain fed arable farming in summer, in the uplands and practicing small scale irrigation of high valued short season and quick maturing vegetable crops in the more fertile and moist vleis and dambos as a mechanism for coping with climate change and drought especially in semi-arid areas. The infertile sandy areas at the top of the catenae have generally been left out mainly for summer grazing (Owen *et al.,* 1995) because of their greater susceptibility to leaching and erosion than wetland soils.

Conclusion

For purposes of identifying site potential for agriculture and rural development planning and where detailed and formal land and soil investigations would probably be difficult because of the time and cost implications involved in conducting them, the assessment of vegetation physiognomic structure and species composition would be more appropriate as an approach to land use planning especially in communal areas than conventional, disciplinary and commodity biased approaches. This is because of the clear physiognomy patterns vegetation makes on the land scape as well as the close associations individual species have with site potential and land management problems. Besides, existing indigenous technical knowledge (ITK) in vegetation and site potential assessment would be easier to apply in participatory land use planning in communal areas than in conventional land capability approaches. Therefore, the full potential for exploiting ecosystem or landscape variability may go unnoticed if the biases of conventional land capability system ways prevail in land use planning especially in communal areas.

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14. Short-term Impact of Clearing Savanna (*Miombo*) Woodlands and Cropping on Greenhouse Gas Emissions in Zimbabwe

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Abstract

Forests are important sinks of greenhouse gases (GhGs) through primary production, and changes in forest area have serious implications on the GhG balance. Rapidly evolving agrarian reforms in Southern Africa have been characterized by the abandonment of nutrient-depleted croplands and encroachment into forestlands. We studied the effects of clearing Savanna Woodlands for maize (*Zea mays* L.) production on soil emission of three GhGs; carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), on two contrasting soils during two cropping seasons in central Zimbabwe. Gas samples were collected once a month from plots in undisturbed, only-trees-cleared and cleared-and-cultivated woodlands with-and-without mineral nitrogen (N) application. Results showed a positive correlation (P <0.01) among CO_2 (8.4 – 209 mg CO_2-C m^{-2} hr^{-1}), CH_4 (-654 – 4389 µg CH_4-C $m^{-2}hr^{-1}$) and N_2O (0 – 222 µg N_2O-N $m^{-2}hr^{-1}$) emissions, and significant differences (P <0.05) in the emissions with land-use, soil type and sampling date. The least CO_2 emissions occurred in cultivated-woodlands without N application on both clay and sandy soils (means, 47.6 and 36.2 mg CO_2-C $m^{-2}hr^{-1}$, respectively), while the highest CO_2 emission occurred in cultivated-woodlands amended with 120 kg N ha^{-1} mineral fertilizer on clay soil (mean, 88.3 mg CO_2-C $m^{-2}hr^{-1}$). With respect to N_2O and CH_4 emissions, variable site and land-use effects were only observed and these depended on sampling dates (soil moisture content and temperature regimes). The highest emissions occurred on clay soil in cultivated-woodland with 120 kg N ha^{-1} mineral fertilizer under the highest soil moisture levels (16-19 %). The least emissions occurred on sandy soil under the least soil moisture levels (4-8 %), irrespective of land-use. It was concluded that, in the short term, cultivation of *Miombo* woodlands, aided by application of mineral N, significantly contributes to additional greenhouse gases in the atmosphere and therefore adds to global warming and climate change.

Key words: Greenhouse gases, land-use change, maize, mineral N fertilizer, savanna woodland

Introduction

Additional levels of atmospheric carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), the primary greenhouse gases (GhGs), are to a significant extent a result of human disturbance of natural systems and processes controlling nitrogen (N) and carbon (C) cycling. These processes, taking place within ecosystems like forest and cropland, respond to external drivers such as climate, management and land use (MacDonald *et al*., 1996; Compton and Boone, 2000). Forests are considered GhG sinks through photosynthesis (Baritz and Strich, 2000; Milne *et al*., 2000), and managed forests in Zimbabwe have capacity to take away an estimated 81 000 Gg of CO_2 per annum (Zhakata *et al*., 1998). However, deforestation followed by cultivation would generally increase soil respiration and reduce soil organic matter content (Chidumayo and

Kwibisa, 2003; Chen *et al*., 2005), thereby making soil a source of additional GhG in the atmosphere, depending on management practice. According to Kundhlande *et al*. (2000), the estimated economic value of C sequestration in Zimbabwe's woodlands of both Communal and State Forests is substantial, but 25% lower (ZW$/ha basis) than the value of converting these lands to individually held croplands. However, due to lack of adequate knowledge on the scale of GhG emission following such land conversion, the environment cost of this practice was not effectively weighed.

Zimbabwe's vegetation is largely characterized by Savanna (*Miombo*) Woodlands (Figure 14.1). *Miombo* is a vernacular word adopted to describe woodland ecosystems dominated by trees in the genera *Brachystegia*, *Julbernadia* and/or *Isoberlinia* (*Leguminosae*, sub-family *Caesalpinoieae*) (White, 1983). In Zimbabwe, *Miombo* woodlands cover about 40% or approximately 156 000 km^2 of vegetation distribution in the country (SASRN, 2001, and an estimated area of 2.7 million km^2 in Southern, Central and Eastern Africa (Frost, 1996). The livelihoods of people and wildlife communities in these regions is dependent on resources (incl., habitat) and products (incl., wild foods and firewood) drawn from *Miombo* woodlands (Clarke, 1996; Wuta, 2004).

The total natural forestland in Zimbabwe was estimated at 18.9 million ha (about 48 % of total land area), against about 3.4 million ha cropland (FAO, 2002; EarthTrends, 2003). However, these figures have not been constant as approximately 70 000-100 000 ha of the woodland area is converted to cropland every year (Moyo *et al*., 1991). This environmental dilemma has been described by Hanao and Baanate (2006) as the current focus of global climate change debates, and resource conservation and policy development in Africa. The magnitude of impact of this phenomenon on GhG fluxes in Zimbabwe, and Southern Africa in general, could be of major significance to global climate change and therefore requires research to assess its impact.

Soils are the main sources of N_2O (55-65%) and CH_4 (60-70%) in the atmosphere, with nitrifiers, denitrifiers and methanogens considered the most important soil microbial sources (Granli and Bockman, 1994; Conrad, 1999). The clearing of forestland and cultivation of forest soils has potential to increase soil aeration, temperature and microbial decomposition of organic materials. This decomposition of organic sources of N (producing CO_2) may (at high soil moisture levels) reduce soil O_2 levels and increase microbial demand for CO_2 and NO_3^- as electron acceptors, thereby producing CH_4 and N_2O (Velthof *et al*., 2003). Consequently, the replenishment of soil N in the trees-cleared and cultivated land may increase primary production and C sequestration (Smith *et al*., 2005), but may also further increase microbially-mediated decomposition in soil, increasing soil emission of GhG (Mosier *et al*., 1998). These opposing facts are however based on limited observations from Southern Africa, a region where alternate wet and dry seasons are of major importance in GhG emission (Rees *et al*., 2006). Thus, the uncertainties regarding the nature and effects of these interactions need to be addressed.

The objective of this study was to assess the impact of clearing the Savanna (*Miombo*) woodlands and maize-cropping with-and-without N application on soil emission of CO_2, CH_4 and N_2O at two sites with contrasting soils in Zimbabwe.

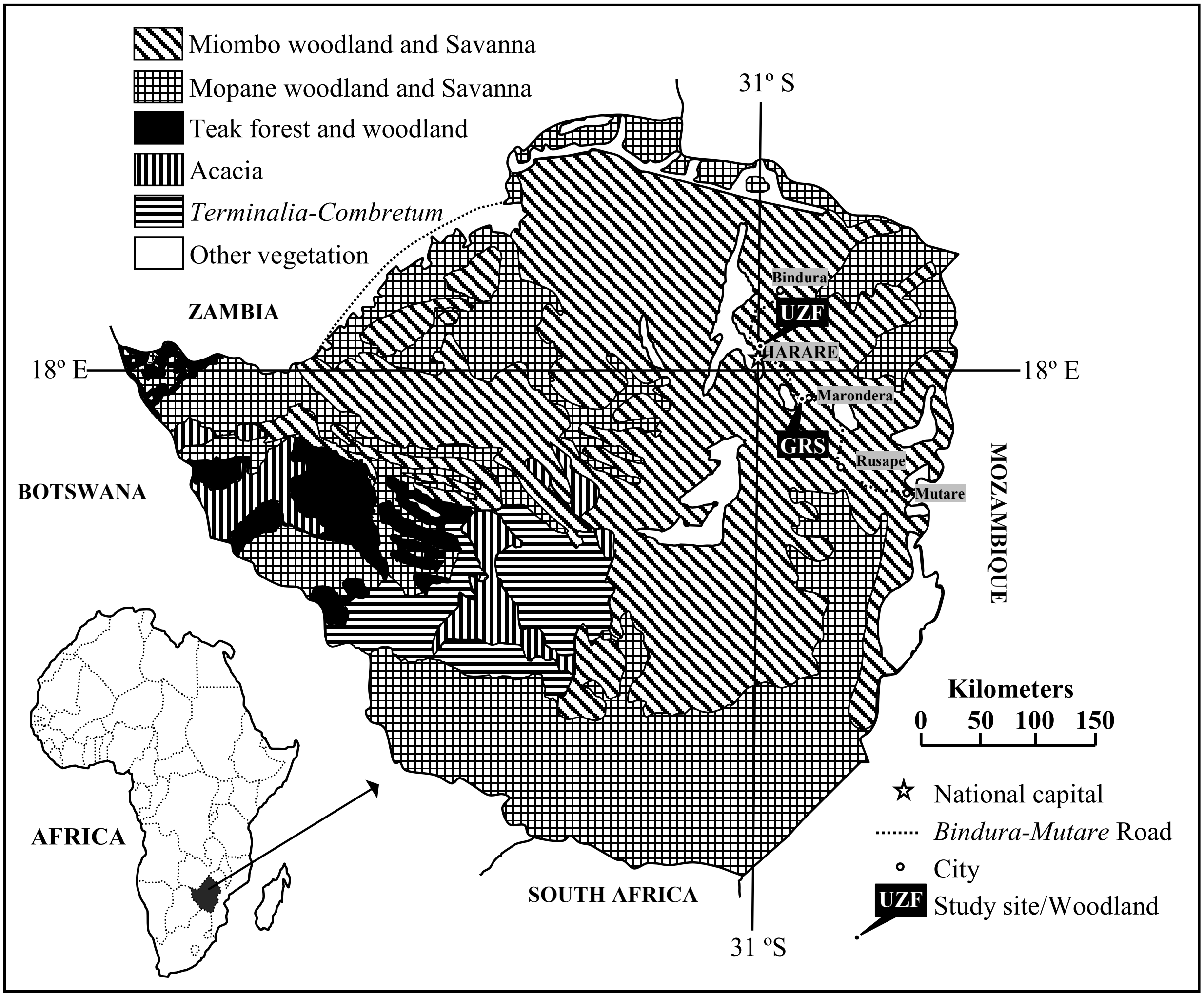

Figure 14.1: The Rattray and Wild (1961)'s early vegetation distribution map for Zimbabwe and the merged locations of the study sites: University of Zimbabwe Farm (UZF) and Grasslands Research Station (GRS).

Materials and Methods

Study Site

University of Zimbabwe Farm (UZF) is located some 15 km north of Harare (31° 00' 48" E; 17° 42' 24" S), while Grasslands Research Station (GRS) is located 67 km east of Harare (31º 29' 00" E; 18º 10' 14" S) (Figure 14.1). The UZF is 2000 ha in extent, and subdivided into 850 ha arable, 1050 ha grazing and 100 ha woodland and farm buildings (Chimbetete, 2008). Typical mixed *Brachystegia spiciformis* and *Julbernardia globiflora* occupy most of the woodland area. The GRS is one of the four National Livestock and Pasture Research Stations in Zimbabwe, covering 2700 ha of land, subdivided into 300 ha arable, 2200 ha grazing and 200 ha of woodland, roads, buildings and wasteland (MOA, 2007). Vegetation at GRS is wooded scrubland with *Terminalia sericea* and *Burkea Africana*, in association with *Combretum* and *Acacia* species. *Brachystegia spiciformis* and *Julbernardia globiflora* occur in places (including the one selected for this study). The grasslands at both UZF and GRS are predominantly occupied by *Hyparrhenia* species.

The two sites experience a sub-tropical climate, and embody the country's prime agroecology with maize (*Zea mays*) as the dominant crop. Soils at UZF are red clays derived from dolerite, while GRS has brown medium-grained sandy-loam soils derived from granite. Other soil and site characteristics of the selected sites are given in Table 14.1. Similar to observations by Baldock *et al*. (1991), granite and dolerite terrains frequently carry similar indigenous vegetation, but clays (UZF) naturally lead to more prolific growth than sandy-loams (GRS).

Experimental Treatment and Management On-Station

The experiment was established at UZF and GRS in December 2006 and conducted during the 2006/2007 and 2007/2008 cropping seasons. Sites were selected in the woodlands, within 50 m from the border between woodland and cropland for easier access and security. Four treatments were introduced, each on a plot measuring 4 m x 6 m in gross area, arranged in a randomised complete block design with four replicates. The treatments were: (i) undisturbed woodland, (ii) only trees cleared woodland, (iii) cleared-and-cultivated (maize-cropped) land without mineral-N fertiliser input, and (iv) cleared-and-cultivated (maize-cropped) land with 120 kg ha^{-1} of mineral-N fertiliser.

The plot boundaries were put using metal pegs, leaving 0.5 m between plots and 2 m between blocks. The clearing of tree stands from just above-ground was done once using an axe, while cultivation was done manually using hand picks to achieve a plough depth of about 15-20 cm. A medium maturity maize variety (SC513) was planted on all cultivated plots at 0.90 m x 0.45 m spacing, with two seeds per planting station. Mineral-N fertiliser (ammonium nitrate) was applied, 50% at planting and the remainder at six weeks after planting each season. In addition, an annual basal application of P (30 kg ha^{-1}, as single super phosphate) and K (30 kg ha^{-1}, as muriate of potash) was done at planting on all cropped plots. The maize crop was kept weed-free during each cropping seasons by hand-hoeing.

Sampling

Gas

Gaseous emissions from soil were trapped using open-bottomed and transparent polythene chambers with a trapping area of 0.40 m x 0.28 m, perpendicular height of 0.2 m and a net volume of 19 dm^3. The chambers had rubber septa on the top centre to facilitate sampling using a syringe. Each chamber was placed above the sampling area (located randomly) within a plot. To avoid, as much as possible gas escaping through any poor contact between soil surface and chamber edges, a small chisel was used to fasten this seal with surrounding soil. This was particularly important on non-cropped plots and when the surface soil was dry. The emitted gas was collected into pre-evacuated 10 cm^3 glass vials using a 50 ml syringe, immediately after securing the chamber on the sampling area and after one-hour of trapping the gas. Gas sampling was done once a month during two cropping seasons targeting, as much as possible, some key events such as precipitation and fertilization. The gas samples were stored in glass vials in the dark at room temperature before being analyzed for N_2O, CH_4 and CO_2.

Soil

Soil samples were collected, initially and following each gas sampling, using a bucket auger at 0-15 cm depth, and at two places at the location where a gas chamber was placed in each plot. The samples were stored in a freezer upon arrival at the laboratory. Soil temperature was measured in-situ at three randomly selected positions within each plot using digital thermometers with 10 cm long stainless steel probes. The soil temperature and air temperature were measured at the first and second gas collection (time zero and time one hour) from each plot. Soils were analysed for moisture and mineral-N (NH_4^+-N and NO_3^--N) concentration.

Plant Material

The maize crop was harvested at physiological maturity (18 and 16 weeks after planting in the 2006/2007 and 2007/2008 seasons, respectively). This was 5-6 week earlier than normal harvest time, mainly a consequence of severe moisture stress at UZF (2006/2007) and GRS (2007/2008) experienced towards the tasseling stage which nullified grain yield, and also in order to recover all above ground biomass. The harvesting was conducted by taking all above ground crop material within a net plot area of 3 m x 3 m. Harvested crop materials were weighed, and a sub-sample of 3-4 whole-plants was collected from each plot for moisture correction and estimation of total plant N and C.

Meteorological Data

Rainfall data was collected daily at 09:00 hrs from a rain gauge at each experiment site. The data for daily maximum and minimum temperatures were gap-filled using meteorological data from the Grasslands Station (GS.877) run by the Department of Meteorological Services (Ministry of Agriculture), and at UZF from the Automatic Weather Station (AWS) run by the Department of Physics (University of Zimbabwe). The GRS.877 is located within the Grasslands Research Station (GRS) at 1794 m from our experiment site in the south-west direction, and records daily data for the national meteorological department. The AWS is located within the University of Zimbabwe Farm (UZF), at 498 m from our experiment site in the north-western direction, and the station records data every 30 minutes.

Analysis of Samples

Gas

Nitrous oxide (N_2O), CH_4 and CO_2 in gas samples were quantified by Gas Chromatography at the Department of Forest Ecology of the Federal Research and Training Centre for Forests, Vienna, Austria. The gas samples were first transferred (5 ml) into 10 ml headspace with aluminium caps, ideal for the auto-sampler of the Gas Chromatograph (Agilent ChemStation). In order to reduce negative pressure in the withdrawal vials another syringe was used to simultaneously inject a solution of 1% KCl to take the space of withdrawn gas. The KCl solution was added in the water to avert the diffusion of GhGs into the water, while an hour of pre-boiling of this solution was meant to take away pre-dissolved gases in the water (Pfeffer *et al*., 2007). Thomas and Adams (1965) measured the diffusion coefficients of CO_2 and N_2O, and established that the solubility of these gases is lower in aqueous solutions than in pure water. A hot Electron Capture Detector (ECD) was used for N_2O analysis, while CO_2 was measured using a Flame Ionization Detector (FID) after catalytic conversion to CH_4 in pure He carrier gas. Methane was measured in the same sample. The fluxes of N_2O, CH_4 and CO_2 were calculated as the differences in concentration between sampling time zero and time one hour.

Soil

Soil moisture, NH_4^+-N and NO_3^--N analyses were carried out simultaneously from fresh samples (kept frozen) in the Soil Testing Laboratory of the Chemistry and Soil Research Institute, Harare (Zimbabwe) using the methods described by Okalebo *et al.* (1993). Mineral-N was extracted by mechanically shaking 5 g of a soil sample with 50 ml of 2M KCl for one hour, and filtering. Ammonium-N was determined after steam distillation of the extract in MgO, trapping the ammonium-N in boric acid plus indicator (bromocresol-methyl red) solution. The distillate (50 ml) was titrated with 0.005 M H_2SO_4. Nitrate-N was determined in the same sample by adding Devarda's alloy to reduce nitrate-N to ammonium-N and distilling again into fresh boric acid, followed by titration with 0.005 M H_2SO_4. Soil moisture was determined gravimetrically as weight loss on oven drying at 105 ºC till constant weight. The soils were air dried and ground to pass through a 2-mm sieve before further analyses reported elsewhere.

Plant

Plant moisture, total N and C estimates were conducted in the Foliar Analysis Laboratory of the Chemistry and Soil Research Institute, Harare (Zimbabwe) using the methods also described by Okalebo *et al.* (1993). Dry matter was determined by weight difference upon oven drying at 70 ºC till constant weight. The dry plant samples were ground to pass through a 2-mm sieve. Total N content was determined using the semi-micro Kjeldahl method (Bremmer and Mulvaney, 1982), while plant C was estimated from organic matter (loss in weight after slow ignition in a muffle furnace at 650 ºC overnight). A conversion factor of 1.724 was used to convert organic matter to organic C based on the assumption that organic matter contains 58% organic C (i.e., g organic matter/l.724 = g organic C) (Okalebo *et al*., 1993; Nelson and Sommers, 1996). Three replicates were made by sub-sampling each sample in the laboratory. Before ashing the samples were pre-heated in an oven at 70 ºC to correct for any absorbed moisture.

Data Analysis

Homogeneity of variances and normality tests were carried out on the data using the Levene's and Kolmogorov-Smirnov's Tests, respectively, at 5 % level. The data did not meet all assumptions of the Fisher-founded Analysis of Variance (Gomez and Gomez, 1984) even after transformation, and hence the Kruskal-Wallis one-way analysis of variance by ranks (Genstat, 2003) was used to establish any significant treatment responses (P < 0.05). A pair-wise separation of significantly different treatment means was done using the Mann-Witney test. Genstat 7.2 (Discovery Edition, Lawes Agriculture Trust UK) and SPSS 8.0 (SPSS Inc., USA) statistical packages were used in the statistical analysis of data.

Results

Weather Conditions and Seasons Quality

The 2006/2007 cropping season, officially declared a drought nationally, was drier (UZF total = 596 mm; GRS total = 562 mm) than the 2007/2008 season (UZF = 996 mm; GRS = 811 mm). Compared to the long-term seasonal averages (Table 14.1), total rainfall deviation at GRS was -38 % and -10 % for the 2006/2007 and 2007/2008 seasons, respectively. Similarly, for UZF the deviation was -30 % and +17 % for the 2006/2007 and 2007/2008 seasons, respectively. Rainfall distribution (Figures 14.2b; 14.2d) was poor at UZF in the 2006/2007 season resulting in severe moisture stress which negatively affected N-uptake after the second fertiliser application and crop performance at tasseling stage (February). The same poor rainfall distribution and effects were observed at GRS the following season in which no rain fell in February 2008. The air temperatures in the two cropping seasons (Figures 14.2a; 14.2c) generally suggested a decrease in the average maximum temperature at GRS in the 2006/2007 season (26.0 ºC) compared to the long-term annual averages (31.1 ºC, Table 14.1).

Table 14.1: General characteristics of the study sites at the University of Zimbabwe Farm (UZF) and Grasslands Research Station (GRS) in Zimbabwe

Characteristic	**UZF**	**GRS**
Altitude, m above sea level	1505	1637
Mean annual rainfall, mm yr^{-1}	850	900
Mean annual temperature, ºC	16-20	15-20
Mean maximum temperature, ºC	25 °C	31.1 °C
Mean minimum temperature, ºC	12 °C	8.4 °C
Soil type, FAO	Chromic luvisol	Haplic lixisol
Soil parent material	Dolerite	Granite
Slope, %	2-3	< 2
Soil pH (in 0.01M $CaCl_2$)	6.5	4.4
Bulk density, g cm^{-3}	1.31	1.82
Soil organic C, %	1.10	0.98
Base saturation, %	53	51
Cation exchange capacity, $cmol^{(+)}$ kg^{-1}	8.4	4.3
Clay content, %	51	11
Soil texture, FAO	Clay	Medium grained sandy-loam

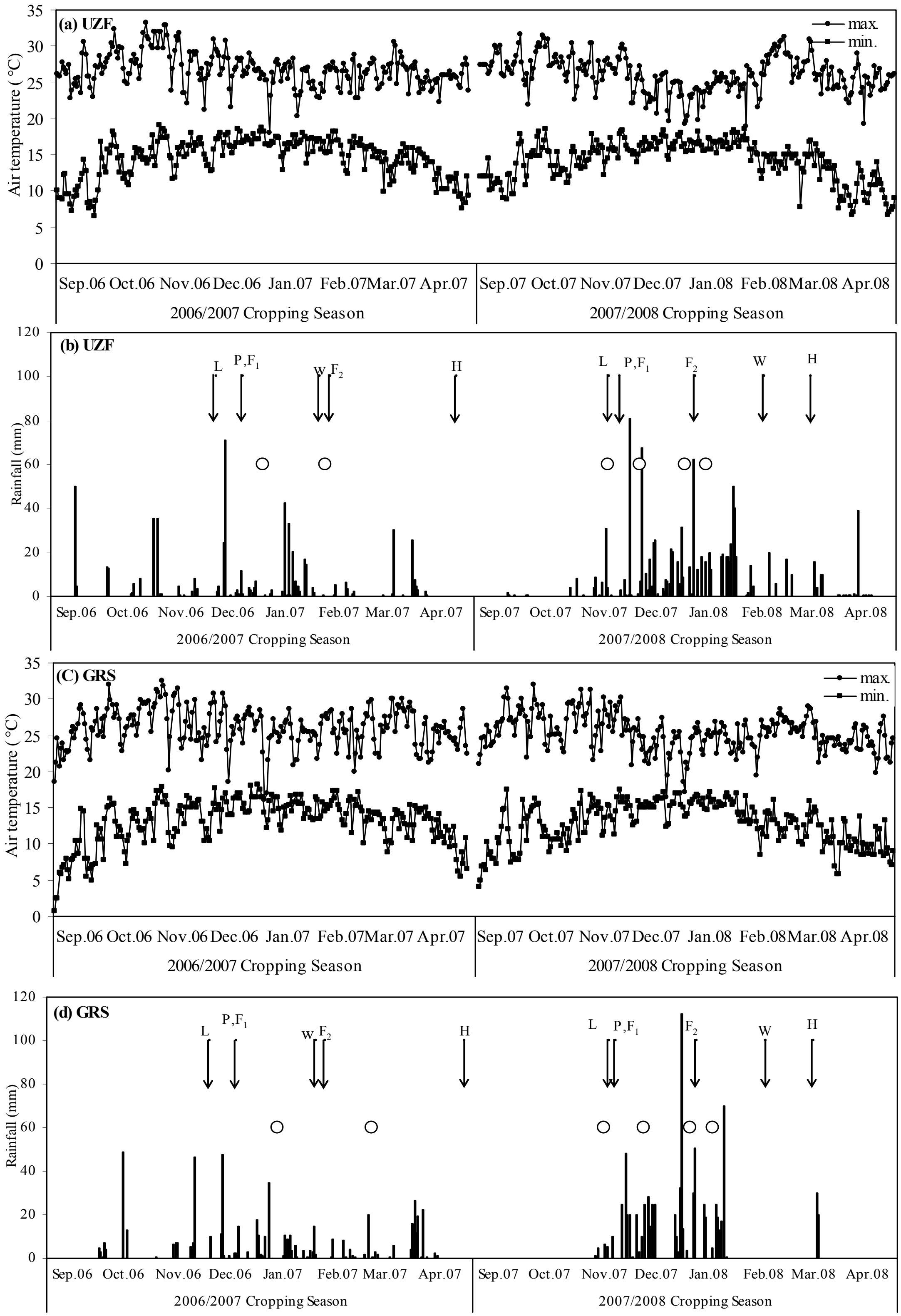

Figure 14.2: Air temperatures and rainfall distribution during two cropping seasons at University of Zimbabwe Farm (UZF) and Grasslands Research Station (GRS), Zimbabwe. Some key events: Land preparation (L), Planting (P), Fertilization (F), Weeding (W) and Harvesting (H) are indicated by arrows while gas sampling dates are marked by circles.

Carbon Dioxide Emission

Soil emission of CO_2 (range, 8.4-209 mg CO_2-C m^{-2} hr^{-1}) varied significantly (P <0.05) with cover type, soil type (site) and mineral-N fertiliser application (Figure 14.3). At UZF (red clay) the cleared-and-maize cropped land receiving 120 kg fertiliser-N ha^{-1} had the highest CO_2 emission (mean, 96.1 mg CO_2-C m^{-2} hr^{-1}), while the cleared-and-maize cropped land without fertiliser-N input had the least emission (mean, 46.0 mg CO_2-C m^{-2} hr^{-1}). The CO_2 emissions from undisturbed- (mean, 57.9 mg CO_2-C m^{-2} hr^{-1}) and only-trees-cleared (mean, 68.1 mg CO_2-C m^{-2} hr^{-1}) woodlands were comparable. At GRS (sandy loams) the cleared-and-cropped land without fertilizer-N input also had the least CO_2 emission (mean, 35.0 mg CO_2-C m^{-2} hr^{-1}) which was however comparable with the only-trees-cleared woodland (mean, 34.1 mg CO_2-C m^{-2} hr^{-1}). The highest CO_2 emission at GRS was found in the undisturbed woodland (68.9 mg CO_2-C m^{-2} hr^{-1}).

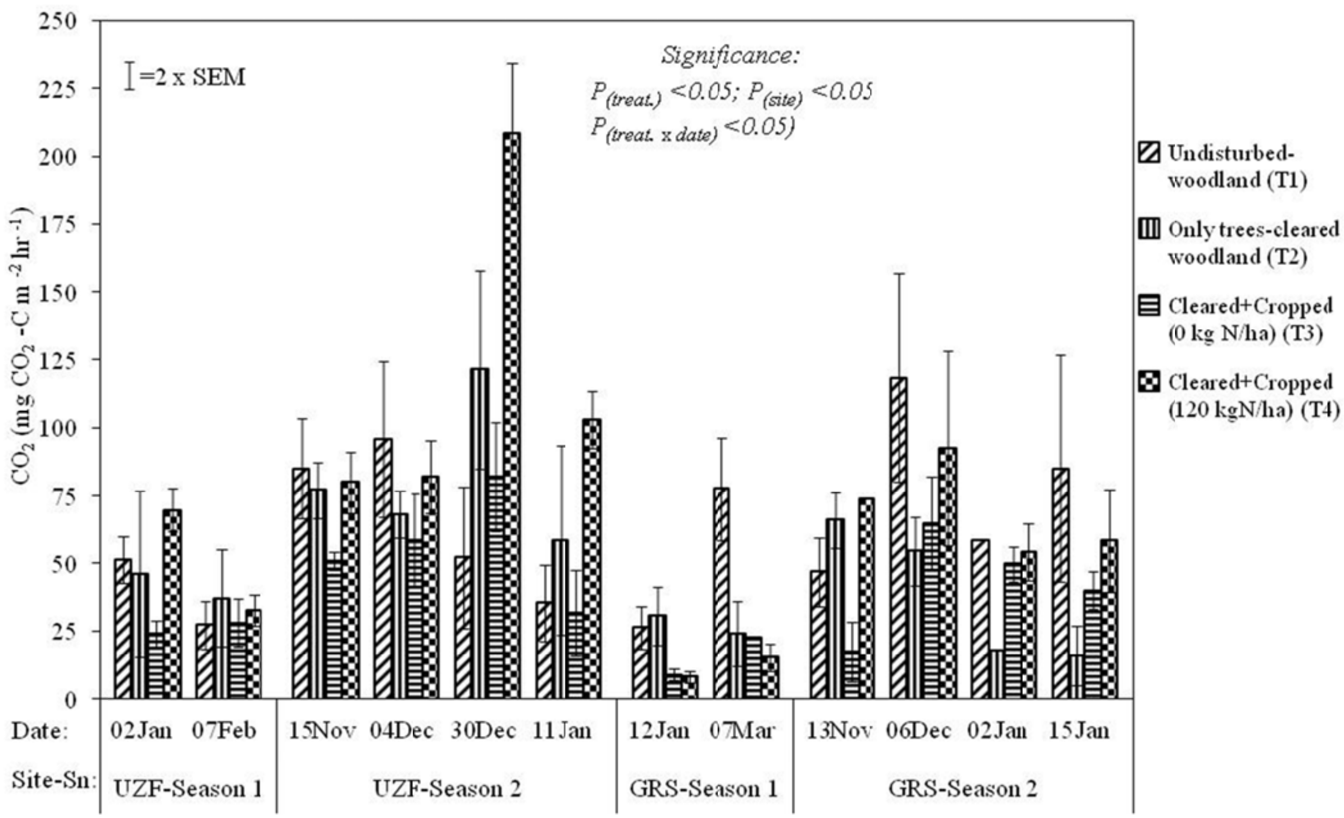

Figure 14.3: Soil emission of carbon dioxide (CO_2) on undisturbed- (T1), only-tree cleared- (T2), and cleared-and-cultivated (maize-cropped) *Miombo* woodlands with-and-without nitrogen supply (T4 and T3, respectively) at the University of Zimbabwe Farm (UZF) and Grasslands Research Station (GRS) sites. The error bars denote Standard Errors of Means.

Sampling date had a significant effect on CO_2 emission, which was also dependant on cover type and mineral-N fertilization. The highest CO_2 emission of 30 Dec. 2008 (209 mg CO_2-C m^{-2} hr^{-1}) was on a cropped and clay soil receiving mineral-N fertiliser, while the least emission of 12 Jan. 2007 (8.4 CO_2-C m^{-2} hr^{-1}) was on cropped and sandy loam also receiving mineral-N fertiliser. However, this least CO_2 emission also coincided with the least soil water content of 5.4%

relative to 19.2 % soil water content on 30 Dec. 2008 (Figure 14.4b). Soil water content (range, 4.4-19.2 %) was considerably higher at UZF (clay) than GRS (sandy loam) but was not significantly affected (P >0.05) by cover type (means, 11.3-12.0 %). However, cover type was significantly responsible for soil temperature variability among the treatments (Figure 14.4a), in which lower soil temperatures were found in undisturbed-woodland (mean, 25.7 ºC) than in trees cleared- and maize cropped lands (means, 29.0-30.1 ºC).

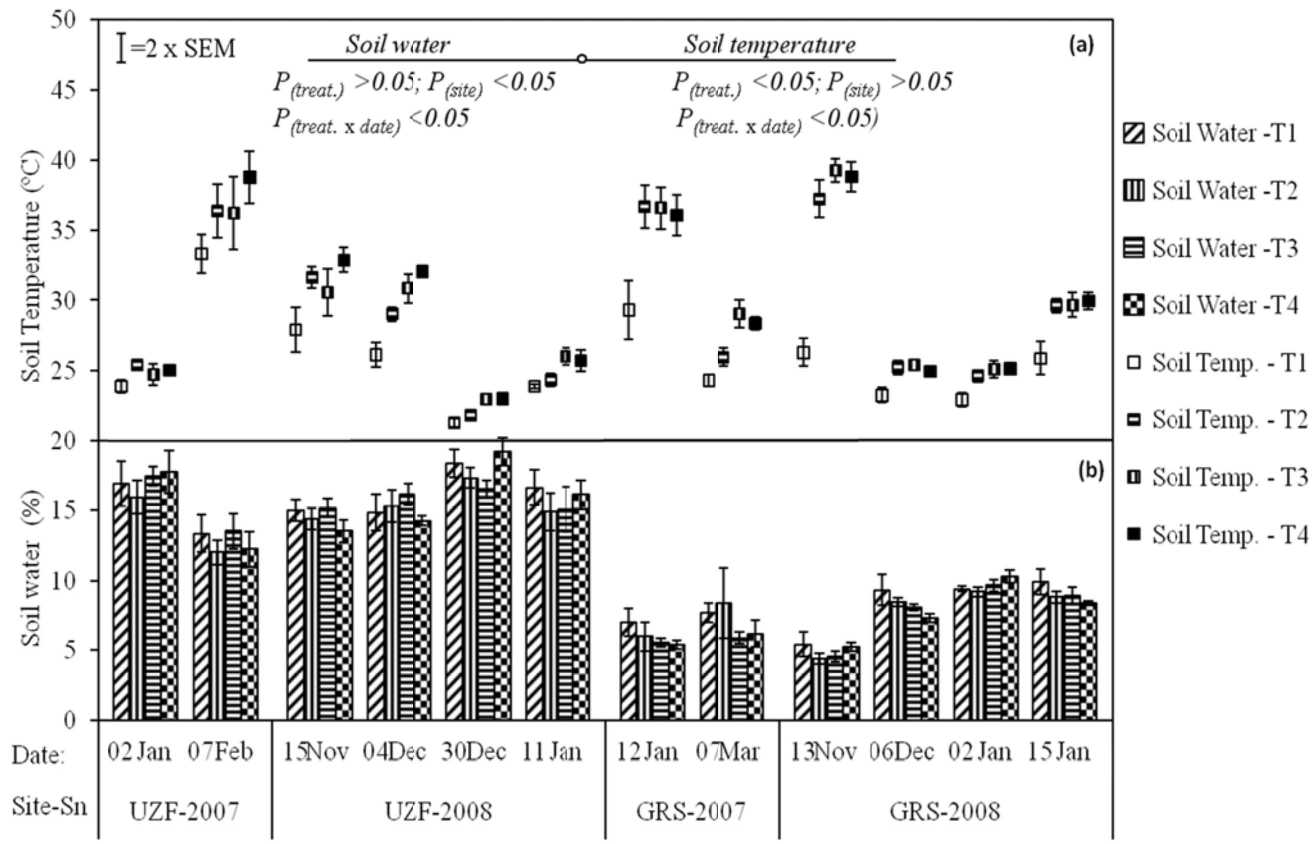

Figure 14.4: The *in-situ* temperature (a) and water content (b) of soils from undisturbed- (T1), only-tree cleared- (T2), and from cleared-and-cultivated (maize-cropped) *Miombo* woodlands with-and-without N supply (T4 and T3, respectively) at the University of Zimbabwe Farm (UZF) and Grasslands Research Station (GRS) sites. Error bars denote Standard Errors of Means.

Methane Emission

Methane emission from soil ranged from -0.65 – 4.39 mg CH_4-C m^{-2} hr^{-1}, and like CO_2, showed sampling date-dependence (and season-dependence) responses to treatment (P <0.05), but there were no significant site effects (Figure 14.5). The average CH_4 emission in the 2006/2007 cropping season did not exceed 10 µg CH_4-C m^{-2} hr^{-1} at both UZF and GRS sites, while in the following season average emissions were 1010 µg CH_4-C m^{-2} hr^{-1} at UZF and 1170 µg CH_4-C m^{-2} hr^{-1} at GRS. Results showed occasional consumption of CH_4, which was observed mainly from only-trees cleared woodlands at both sites, but also from the undisturbed- and cropped woodland on single instances at UZF. The consumption ranged from 3.9-654 (median, 113) µg CH_4-C m^{-2} hr^{-1}.

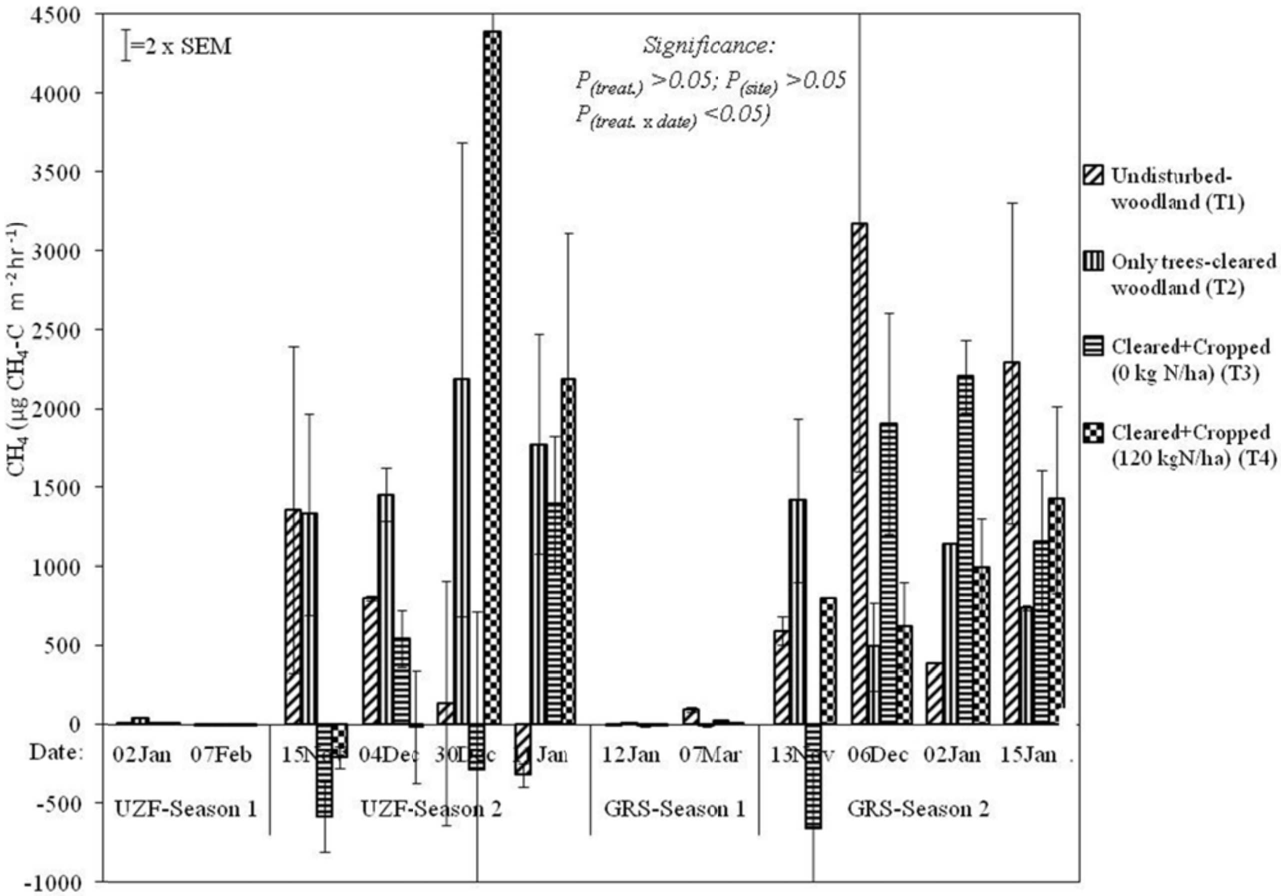

Figure 14.5: Soil emission of methane (CH_4) on undisturbed- (T1), only-tree cleared- (T2), and cleared-and-cultivated (maize-cropped) *Miombo* woodlands with-and-without mineral-N fertiliser application (T4 and T3, respectively) at the University of Zimbabwe Farm (UZF) and Grasslands Research Station (GRS) sites. The error bars denote Standard Errors of Means.

Nitrous Oxide Emission

Emission of N_2O (range, 0 – 222 µg N_2O-N m^{-2} hr^{-1}) was positively correlated with CO_2 emission (P <0.01) as well as soil water content (P <0.05). The effects of cover type and mineral-N fertilization on N_2O emission also depended on the sampling dates (and partially on soil water content) (Figure 14.6). Soil water content related to N_2O emission through the equation: $[N_2O]$ = 2.107 x (% water) + 15.47 (R^2 =4.6 %). However, subdividing the data according to site and treatment showed that at UZF (clay), soil water content affected N_2O emission on mineral-N fertilised plots through the equation: $[N_2O]$ = 11.72 x (% water) -121.9 (R^2 =29.8 %); and the only-cleared woodland through the equation: $[N_2O]$ = 18.80 x (% water) - 215.7 (R^2 =39.9 %). Emission of N_2O from the undisturbed- and cropped woodland without N-fertiliser did not respond to soil water content ($R^2 \approx 0$).

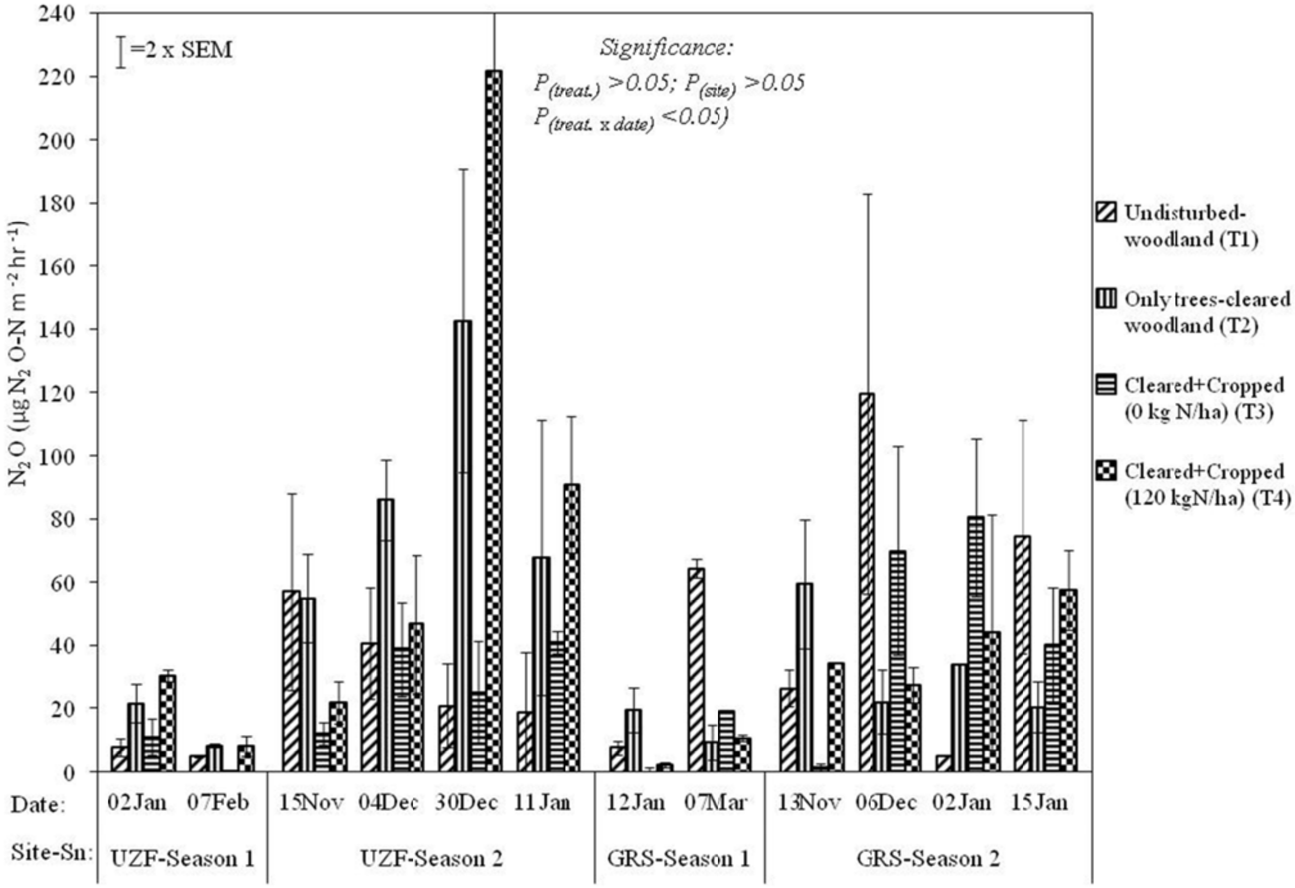

Figure 14.6: Soil emission of nitrous oxide (N_2O) on undisturbed- (T1), only-tree cleared- (T2), and cleared-and-cultivated (maize-cropped) *Miombo* woodlands with-and-without mineral-N fertiliser application (T4 and T3, respectively) at the University of Zimbabwe Farm (UZF) and Grasslands Research Station (GRS) sites. The error bars denote Standard Errors of Means.

Similarly, at GRS (sandy loam), soil water content affected N_2O emission on mineral-N fertilised plots through the relationship: $[N_2O]$ = 4.57 x (% water) -13.60 (R^2 =12.4 %); and the cropped woodland without N-fertiliser through: $[N_2O]$ = 12.75 x (%water) -53.58 (R^2 =29.0 %). The undisturbed-woodland also did not show N_2O emission response to soil water content at GRS.

Soil NH_4^+-N (range, 3.3-19.7 mg kg^{-1}) and NO_3^--N (range, 0.04-20.5 mg kg^{-1}) (Figure 14.7), showed a negative and positive correlation with N_2O emission, respectively, but the linear relationships were generally weak: $[N_2O]$ = -3.11 x $[NH_4^+$-N] +51.39 (R^2 =12 %); $[N_2O]$ = 3.63 x $[NO_3^-$-N] -11.99 (R^2 =19 %). Subdividing the data according to site and treatment did not improve the linear regression between the mineral N forms and N_2O emission. The ratio of NH_4^+-N to NO_3^--N in soil increased from the medians of 1.5:1 (UZF) or 0.8:1 (GRS) in 2007 to 16:1 (both sites) in 2008, irrespective of treatment, but the ratios as well as total mineral N (NH_4^+-N plus NO_3^--N) did not relate with soil emission of N_2O (R^2 = 0).

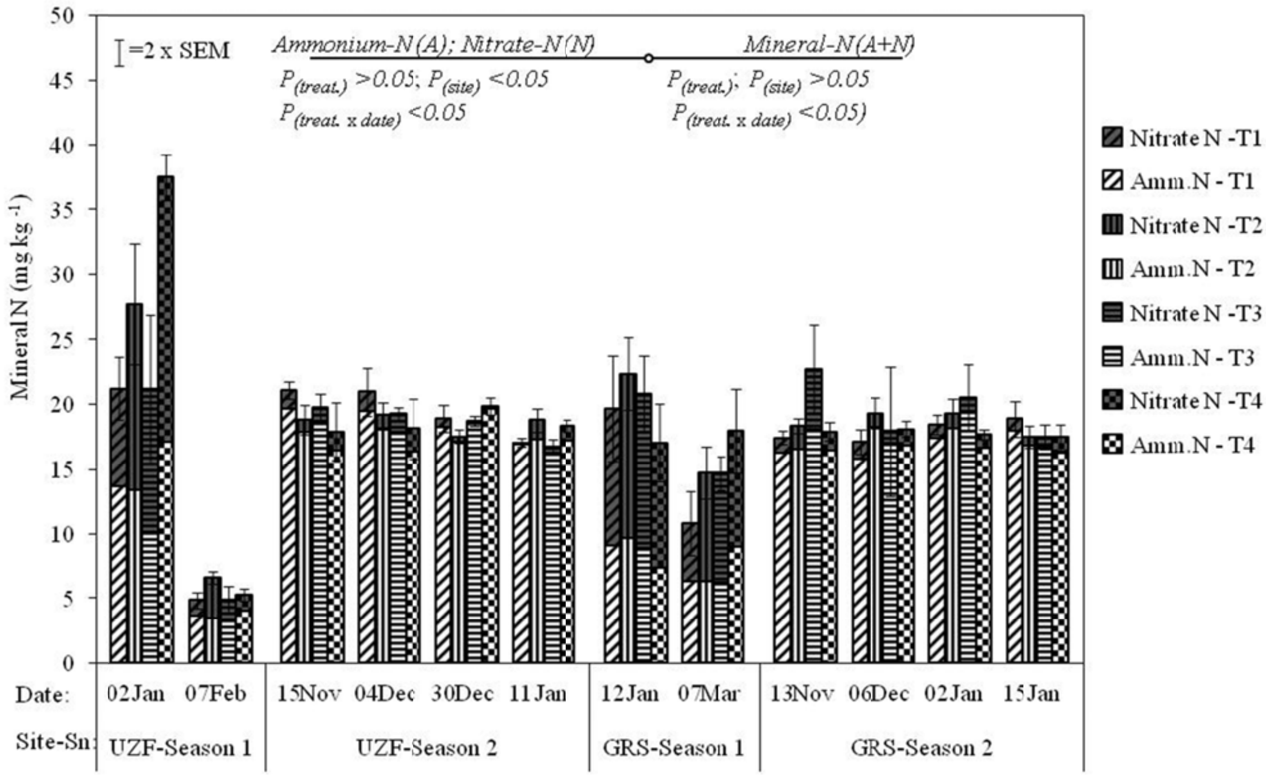

Figure 14.7: Soil mineral-N (ammonium- (Amm.) and nitrate-N) from plots on undisturbed- (T1), only-tree cleared- (T2), and cleared-and-cultivated (maize-cropped) *Miombo* woodlands with-and-without nitrogen supply (T4 and T3, respectively) at the University of Zimbabwe Farm (UZF) and Grasslands Research Station (GRS) sites. The error bars denote Standard Errors of Means for mineral N.

Above-ground Biomass, N-uptake and C Removal

Above-ground biomass of maize showed a positive response ($P < 0.05$) to mineral-N fertiliser application by 1.5 to 3 orders of magnitude relative to non-N fertilised maize (Table 14.2). The severity of moisture stress was more responsible for the variability in above-ground crop biomass between UZF and GRS than soil type. Total N taken up by the crop was generally low and followed similar response to mineral-N fertiliser application. However, the N concentration in maize was not significantly affected by mineral-N fertiliser application in the first season. Plant C removed through the harvest also responded positively to mineral-N fertiliser application although the estimated concentration of plant C in the crop did not vary significantly ($P > 0.05$) with N-fertilization. However, plant C was consistently higher in the second cropping season than in the first.

Table 14.2: Mean crop establishment (ESTAB) proficiency and total N and C contents in above ground biomass (AGB) of maize grown on cleared-and-cultivated *Miombo* Woodlands at UZF and GRS sites in two cropping seasons.

Site and Woodland Status	**ESTAB**	**AGB**	**Total N**	**Total C**	**AGB N**	**AGB C**
	%	**kg ha^{-1}**	**----------%---------**		**--------kg ha^{-1}-------**	
			2006-2007			
UZF: Cultivated, 0 kg N ha^{-1}	81^{a}	305^{a}	1.17^{b}	48.3^{a}	3.5^{a}	147^{a}
UZF: Cultivated, 120 kg N ha^{-1}	79^{a}	753^{ab}	1.33^{b}	48.0^{a}	9.9^{bc}	362^{ab}
GRS: Cultivated, 0 kg N ha^{-1}	69^{a}	805^{ab}	0.98^{ab}	48.1^{a}	7.7^{abc}	389^{ab}
GRS: Cultivated, 120 kg N ha^{-1}	79^{a}	1352^{b}	1.13^{ab}	48.5^{a}	14.9^{bc}	658^{b}
			2007-2008			
UZF: Cultivated, 0 kg N ha^{-1}	85^{a}	601^{ab}	0.75^{a}	50.1^{b}	4.6^{ab}	303^{ab}
UZF: Cultivated, 120 kg N ha^{-1}	81^{a}	1028^{b}	1.17^{b}	50.4^{b}	11.8^{bc}	517^{b}
GRS: Cultivated, 0 kg N ha^{-1}	78^{a}	333^{ab}	1.10^{ab}	50.6^{b}	3.7^{ab}	168^{ab}
GRS: Cultivated, 120 kg N ha^{-1}	71^{a}	911^{b}	1.31^{b}	50.1^{b}	11.7^{bc}	463^{b}
Significance	ns	**	**	**	**	**
CV (%)	15.8	54.1	16.6	1.5	50.9	54.6
Std. Error of the Diff. of Means	8.69	291	0.13	0.51	3.05	145

DISCUSSION

The soil emission patterns of the primary GhGs (CO_2, N_2O and CH_4) and crop productivity responded considerably and systematically to different combinations of cover type, soil type and moisture regime, fertilization and the general cropping season quality. Results show that in these cropping seasons cover type played a role in the regulation of soil temperature. However, the lower soil temperature in the undisturbed woodland with considerable tree canopy cover did not necessarily slow down soil emission of GhGs relative to treatment that had all trees cleared or to the cleared-and-maize cropped treatments. The linear regression between soil temperature and GhG emission was in fact poor (R^2 = 5.6-10.2 %), and negative for all GhGs, e.g. [CO_2] = -2.396 x (temp.) +126 (R^2 = 10.2 %). This could be attributed chiefly to the fact that higher soil temperatures were also associated with dry soils, while under wetter soil conditions (ideal for GhG emission) soil temperatures were generally lower. Soil temperature was not a limitation, and this is in contrast to research findings from temperate climates were GhG emissions from soil are largely temperature dependant (Hiu *et al*., 1999).

The opening of *Miombo* woodlands for cropping, coupled with mineral-N fertiliser application (and high soil water content) were the most important drivers of soil emission of GhGs in the short term. Results suggested that clearing of trees alone, and clearing-and-maize cropping without mineral-N fertiliser application may in fact lower soil emission of GhGs. By removing tree stands, N input from throughfall, stemfall and leaf litter fall is also lost, and according to a study by Wuta (2004) on similar woodland in Zimbabwe these sources can contribute on average about 5.9, 0.1 and 41.6 kg N ha^{-1} to the soil, respectively. The N added to soil through mineral-N fertiliser application and the potential N additions in the undisturbed woodland were however not directly reflected in soil mineral-N concentrations.

Methane consumption (oxidation) could be significant occasional sink for atmospheric CH_4, as observed mainly in only-trees-cleared woodland. A study by Suwanwaree and Robertson (2005) at a site in Michigan with comparable rainfall but lower mean annual temperature found higher oxidation rates of CH_4 in forest soils (30 µg CH_4-C m^{-2} hr^{-1} on average) than in agricultural soils (about 12 % of this). In addition, they found that mineral-N fertilizer addition (100 kg N ha^{-1}) as well as soil disturbance on agricultural land had no detectable effects on methane oxidation.

Results suggested high ammonification tendencies in all cover types, which resulted in high NH_4^+-N: NO_3^--N ratios, but very poor linear regression (R^2, 4.4-10.9 %) between NH_4^+-N or NO_3^--N and GhG emission. Ammonification tends to discourage N losses as N_2O and NO_3^- leaching, and the NH_4^+ produced can be immobilized by plants and microbes, a controlling factor of ecosystem N retention (Burger and Jackson, 2004).

Conclusion

Based on the results of this study, it was concluded that cultivation of *Miombo* woodlands aided by application of mineral N, significantly contributes to additional greenhouse gases in the atmosphere in the short term, and therefore adds to global warming and climate change. On the contrary, clearing of trees alone, and clearing-and-maize cropping without mineral-N fertiliser application may lower soil emission of GhGs, while clearing of tree stands alone may occasionally induce CH_4 consumption. This is however, notwithstanding the negative impact of deforestation on primary production and CO_2 uptake. There was no substantial crop productivity and N-uptake on the cleared-and-maize cropped woodlands, and this was attributed to moisture stress resulting from poor rainfall distribution, but may also open up a potential area for further research particularly targeting full fate of the added N.

Acknowledgements

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15. Indigenous Natural Resources Management Knowledge on the Coasts of Kenya and Tanzania

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Abstract

The coastal areas of Kenya and Tanzania are rich with land and marine resources. The deltas of rivers Tana, Pangani and Rufiji for instance have for many centuries provided livelihoods to many local communities. However, there is scanty information on the mechanisms that are used in the acquisition, dissemination and preservation of local knowledge on natural resource management and utilization among coastal communities. Experience has shown that development efforts that ignore local systems of knowledge and the local environment can fail to achieve their desired objectives. The objective of this survey was to develop a good understanding of the natural resources knowledge available within coastal communities of Kenya and Tanzania, and assess its upkeep for posterity. Data were collected through review of relevant documents, direct field observations; and administering questionnaires and checklists for key informants. Quantitative and qualitative methods were used for data analysis. Sample coastal communities shared their knowledge on natural resources (land and marine) and mechanisms used to accumulate knowledge and experiences. Gender and cross-generational issues in the processes/mechanisms for accumulation, use and passing on of knowledge were captured. Findings indicate that coastal communities consist of people of highly mixed ethnicity and cultures. For most communities knowledge on natural resources is held by the older generation and highly genderised. Local communities demonstrated strong interest and willingness to share knowledge, but generally, traditional healers do not wish to make public their healing knowledge. Although traditional oral passage of knowledge to younger generations still exists, it is weakening because it is no longer obvious that children inherit their parents' livelihood strategies and activities. Exposure to tourism is accelerating the process of change especially for the youth in terms of culture and future livelihood aspirations. With no pro-active mechanisms that promote indigenous knowledge, there are strong views that this knowledge will fade away. Local communities acknowledge that loss of this knowledge would be detrimental to their communities' rich heritage.

Key words: Indigenous communities; natural resource management knowledge; Coastal area; Kenya; Tanzania

Introduction

Knowledge is an important ingredient for effective natural resource management and human development. Experience has shown that development efforts that ignore local systems of knowledge, and the local environment can fail to achieve the desired objectives. Of equal concern is the uncertain status of the knowledge that reflects many generations of experience and problem solving by thousands of ethnic groups across the globe (Ulluwishewa *et al.,* 1997). Very little of this knowledge has been recorded, yet it represents an immensely valuable database that provides humankind with insights on how numerous communities have interacted with their changing environment including its landscape, flora and fauna resources.

Knowledge is not confined to tribal, rural or the original inhabitants of an area. Rather, every community possesses knowledge: be it rural or urban, settled or nomadic, original inhabitants or migrants. In defining knowledge, one must keep in mind the practical needs as well as the research needs. To understand knowledge and practices, one must have a good understanding of the concepts on which they are based (both content and context). This is particularly relevant in cases where intervention or improvement of practices in changing ecological and economic scenarios is aimed at social sustainability.

For the purpose of this study we will discuss indigenous knowledge (IK) and outside knowledge (OK). Indigenous knowledge has two advantages - it costs less to collate and is already accepted by the local community concerned (Kothari, 1995). Indigenous knowledge systems and technologies are often seen to be socially desirable, economically affordable, and are widely believed to conserve resources. Outside knowledge often refers to the knowledge developed by the academia, research institutions and private firms using formal scientific approaches. Thus the acquisition, dissemination and preservation of OK take formal top-down approaches, usually introduced in a given locality by scholars or agents who have undergone education or training (Brush, 1996).

It is sometimes difficult to decide whether a technology or practice indeed is indigenous or adopted from outside, or a blend of local and introduced components (Grenier, 1998). For a development project, however, it does not matter whether a practice is really indigenous or already mixed up with introduced knowledge. What is important is that instead of looking only for technologies and solutions from outside the community, we first look at what is in the community. We then use whichever knowledge is found to be effective. It suggests that IK and OK need to fuse in terms of knowledge, practice and internationally accessible knowledge pool (Kothari, 1995).

An important element when dealing with knowledge is the issue of who keeps what type of knowledge. Within societies there are divisions of labour which define the limits of each individual member by gender, age or other socially defined categories. Thus, persons involved in a particular type of activity may possess certain types of knowledge which could be quite different from persons in another social group. It is interesting to gain an understanding of how such divisions influence knowledge management over time.

The coastal ecosystems of Kenya and Tanzania are rich and unique, bringing together land and sea resources, fresh and salty waters, land and marine resources. The unique ecology they provide makes it possible to cultivate many different types of crops and fish, adapted to saline, semi-saline and fresh water conditions. Coastal human communities are melting pots for many cultures, local and foreign. The mangrove forests provide highly durable wood that is used in the construction of boats at the same time creating fertile conditions for the cultivation of prawns and shrimps.

The East African coastal people have a very long history of interactions with local communities in the hinterland as well as foreigners from many countries, especially Asia, Middle East and Europe. Over the many centuries, these communities have accumulated a lot of knowledge about their livelihood and the natural resources around them which have expanded their scope of knowledge enormously, increasing their ability to avert, overcome or cope with many negative social, economic and ecological conditions. However, their knowledge and experiences are not systematically managed. With time, this knowledge is likely to degrade and disappear. Our challenge was to determine to what extent this hypothesis is true. This survey was intended to provide information on the knowledge systems to facilitate a thorough analysis of problems and opportunities of generating a cross-generational sharing of knowledge.

Objectives of the study

The study objective was to develop a good understanding of the natural resource management knowledge available in the coastal communities of Kenya and Tanzania, and the local mechanisms used for managing it. The specific objectives were:

- To document existing knowledge on natural resource management;
- To explore the methods used for the capture, use, preservation and dissemination of the natural resource management knowledge;
- To understand the mechanisms used by local communities to pass on the knowledge; and
- To understand the roles of gender and youth in the processes in knowledge management.

Location

This study was carried out along the coastlines of Kenya and Tanzania. The choice of locations was inspired by the outcome of the tsunami that hit the Indian Ocean coasts of Kenya and Tanzania in 2004. Globally it was acknowledged that better use of local knowledge could have saved lives.

Kenya

Kenya has over 600 km of coastline and this is one of the most important components of the nation's rich heritage. The Kenyan Coast runs in a south westerly direction from the Somalia border in the north at 1^{o} 41'S to 4^{o} 40'S at the border with Tanzania in the south. It lies in the hot tropical region where the weather is influenced by the great monsoon winds of the Indian Ocean (UNEP, 1998). Coastal Kenya covers an area of about 89370 km^2 with an estimated population of 2.56 million people (KARI, 2005). The area is divided into seven administrative districts which are Kilifi, Kwale, Lamu, Malindi, Mombasa, Taita/Taveta and Tana River. For purposes of this study, only the districts that have a coastline were included (Figure 15.1 and Table 15.1). Therefore, Taita/Taveta and northern Tana River, which are found further in the hinterland were not covered. The area covered lies in the coastal lowlands (CL) up to 250 m above sea level. In addition to farming, the local communities have off-farm activities such as fishing, which is an important source of income.

The ethnic groups in the study areas include the Mjikenda (Digo, Duruma, Giriama, Rabai, Ribe, Kambe, Jibana, Chonyi and Kauma), Bajuni, Pokomo, Orma, Moigo and the Wardei

(Waaijenberg, 1994). In addition, there are other ethnic groups who have settled in these areas such as the Akamba, Luo and Kikuyu.

Table 15.1. Districts and Divisions covered by the study in Kenya

District	***Division***
Kwale	Msambweni
Mombasa	Likoni, Kisauni, Changamwe
Kilifi	Kikambala
Malindi	Malindi, Ganda
Tana River	Kipini, Garsen
Lamu	Amu, Faza, Witu, Kizingitini

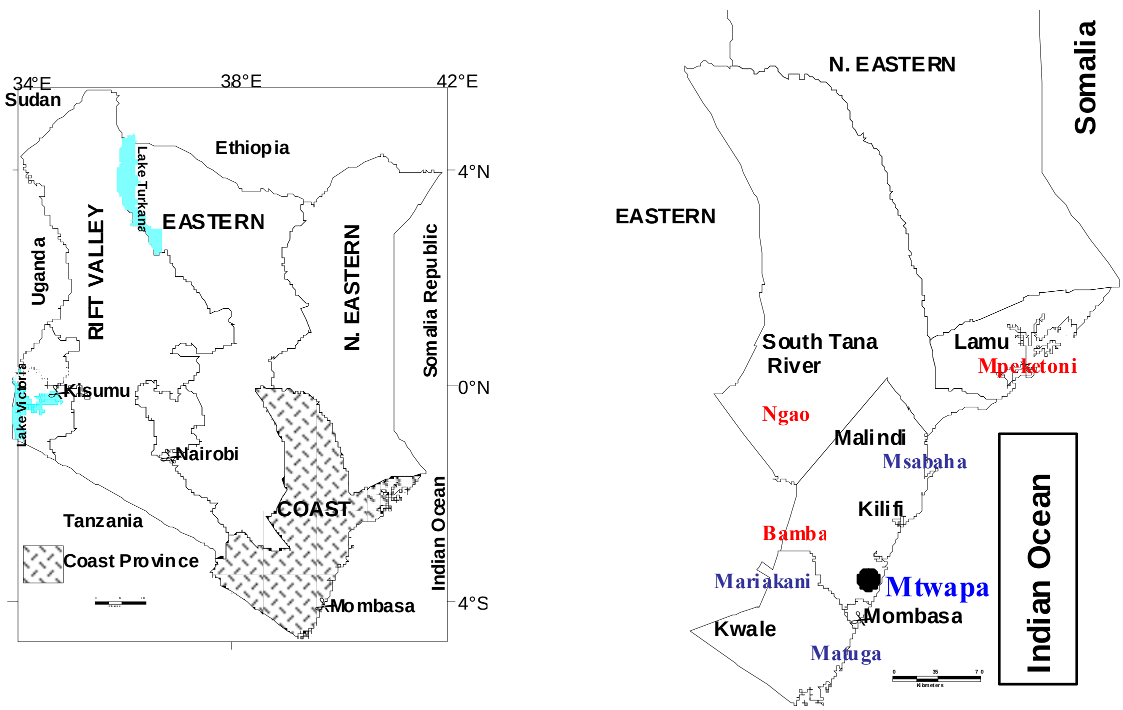

Figure 15.1. Study area in Kenya showing the province, districts and divisions

Tanzania

In Tanzania, the study was conducted along the coastal parts of Tanga, Dar es Salaam and Coastal Regions. The districts and villages covered for each region in the study are shown in Table 15.2 and Figure 15.2.

Socio-economic activities

The Kenya and Tanzania coast is rich in historical and archaeological sites, a testimony to its long and full history depicting centuries of Swahili culture. These are located in Lamu, Malindi and Mombasa districts of Kenya, and Bagamoyo and Pangani districts of Tanzania. They include forts, tombs, ruins of houses and mosques. For the coastal communities, fishing is one of the dominant socio-economic activities. Most of the fish is caught by artisan fishermen who operate between the shoreline and the reef. Fishing plays two major roles; as a source of food contributing over 60 % of protein consumption in some parts, and as a source of income. Salt harvesting is another economic activity. The total area dedicated to salt production in Kenya is about 5000 ha yielding 170,000 tons of salt annually. Limestone deposits are extensive. However, exploitation is governed by local variation in texture, composition and demand. In Bamburi area, north of Mombasa it is used for cement manufacture. Other minerals are iron ore, gypsum and silica sands. Other socio-economic activities include, weaving, trap making, small scale handicraft industries, fish farming, seaweed farming and crab farming.

Table 15.2. Districts and villages studied in Tanzania

S/n	Region	District	Division	Ward	Village
1	Coastal region	Bagamoyo	Mwambao	Dunda	Dunda
		Rufiji	Kikale	Salale	Mchinga/Mfisini
2	Dar es salaam	Kinondoni	Kawe	Kunduchi	Kunduchi
				Mbweni	Mbweni
3	Tanga	Muheza	Mkinga	Manza	Tawalani
		Pangani	Mwera	Mwera	Ushongo mabaoni
				Kipumbwi	Kipumbwi
			Pangani	Pangani West	Pangani West
		Tanga Urban	Chumbageni	Chongoleani	Chongoleani
			Pongwe	Tangasisi	Machuwi
				Tongoni	Tongoni

The ethnic groups living in the study areas include Digos, Bondei, Zigua, Zaramo, Kwere, Ndengeleko and Mdoe

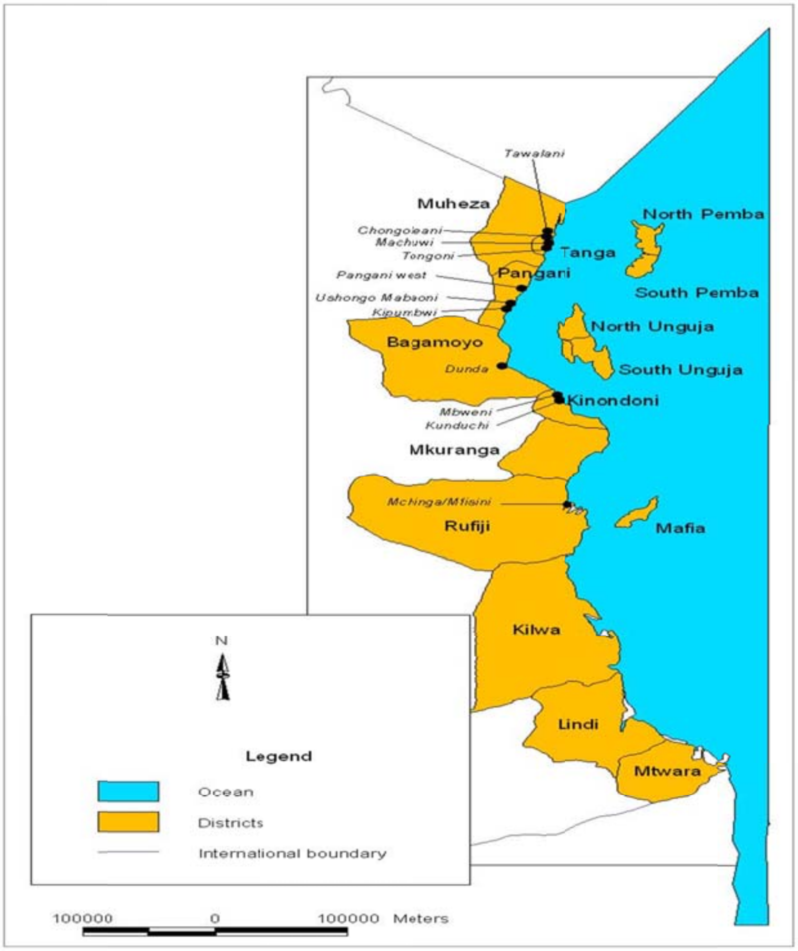

Figure 15.2. Study sites (marked with bullets) along the coastal parts of Tanzania

Data collection methods

Data collection started with an extensive review of available literature. This was followed by the administration of a semi-structured questionnaire to randomly selected persons. These were coupled with field visits/observations and focused group discussions with the local people. Discussions were held with government officials and other relevant stakeholders in the areas especially to confirm demographic data. The study adopted cluster sampling procedure where communities were clustered based on livelihood options. The livelihood options included people engaged in farming, fishing, handicraft, tour guiding and trading. Random samples of 150 people in Kenya and 80 in Tanzania were drawn from the five groups.

The questionnaires served to enhance understanding on natural resource management knowledge and focused on household characteristics and composition, awareness on the available natural resources, uses, main users and knowledge they have on the resources. Different sets of questionnaires were designed for each livelihood category and they focused on the mechanism through which knowledge is acquired, managed, passed on, preserved, and disseminated and its future prospects. Also the questionnaires sought to understand problems encountered in passing on the knowledge to the youths.

A checklist was prepared to solicit information from key informants. A key informant is an individual who is knowledgeable, accessible and willing to talk about the issues under study. Key informants included natural resource officers (government officers), leaders of various associations and groups that utilize natural resources along the coastline, village leaders and old people who were thought to be knowledgeable.

Data collected using questionnaires, direct observations and discussions with informants were analysed quantitatively and qualitatively. Discussions were separated into written presentation/statements through personal interpretations. Qualitative analysis enabled the identification and understanding of existing knowledge and the way people interact with local resources and the environment, and interaction amongst members of the society. Finally quantitative data entry, management and analysis were carried out using Microsoft Excel 6.0 to generate summaries, percentages and frequencies.

Findings in Kenya

Characterization of communities

There were a total of 150 respondents. Ten per cent of the respondents were females. The rest (90 %) were male. Fishing and tour guiding was male dominated with 100 % respondents being male. Females were represented among farmers, crafts and business people: in proportions of 15 %, 20 %, and 20 %, respectively. One of the reasons given was that fishing and tour-guiding were tough activities. The reason for most of the respondents being male could partly be explained by traditional division of labour among men and women in the communities.

The majority of the respondents (80 %) were married, singles (15 %) and widowed (5 %). The large percentage of married respondents may be a reflection of the strong cultural respect of the marriage institution. Their traditions also encourage early marriages to an extent of withdrawing young girls from school to marry them off to their suitors.

Respondents had various levels of education (Table 15.3). However, majority of them had formal education at primary level. The communities have not fully embraced formal education. This could be because of the high poverty levels (62 %). Girls particularly reported neglecting education in favour of early marriages.

Table 15.3. Level of education among respondents

Level of education	**Per cent respondents (%)**
Primary level	53
Secondary level	21
Tertiary level (colleges, universities)	2
No formal education	24
Total	100

Muslims were the majority in the study area (63 %). Thirty five per cent were Christians and 2 % were atheists. Rural households engage in diverse agricultural and non-agricultural activities for their livelihood. In agriculture, food crops grown are maize, cassava, cowpea and rice while coconut, cashew nuts, mangoes, bananas and sisal are a source of cash income. Other activities are fishing, craftwork, tourist service provision and business trading. Fishing appeared to be the most common activity undertaken.

Natural resources available

The respondents named numerous natural resources. These could be grouped into marine, land and mineral resources. Marine resources consist of various fish species, crustaceans, molluscs, coral reef, islands, marine shells turtles and marine parks. Land resources included; farming land, wildlife, mangrove forests, natural forests including the 'Kayas', reeds, stones, sand for building and minerals (limestone). Other unique resources named were ruins of historical buildings and other structures (Pillars) built during the foreign occupation of the coast. The respondents were familiar with different varieties of recourse, mainly those on which they depended on for their livelihood.

Use of natural resources

Communities along the coast utilize natural resources for their livelihood. The resources offer a variety of options. Apart from using fish as food, they also sell fish for income. The experienced fishermen seemed to know where to go for the different types of fish and when certain species of fish could be found. They indicated that they could tell from the sounds of the sea when it was safe to go out for fishing and when to keep away. Land is used for farming crops and livestock keeping for food and income. The same land offers quarries for stone cutting (building materials), gravel and sand. Mangrove forests are used for building poles, boat building, fuel wood and charcoal. Natural forests provide a source of medicine, carving wood (to make sculptures for people and animals, wooden bowls, pictures and key holders), timber, fuel wood and charcoal. Coral reefs provide coral stone for building and sites for visits by tourists. Seawater is used for swimming and snorkelling. Tourists visit various islands, ruins of houses and mosques as tourist sites. Reeds are used to make mats, covers, fans, hats and ropes.

Users of natural resources

Men dominate most activities and are the main users of natural resources. Women use land for agriculture and livestock keeping although they do not own the land. They also use mangrove forests for building poles and sell beadwork and beach wear.

Knowledge on natural resources

Coastal communities have knowledge on the available resources and their uses. This include knowledge on fishing, farming, wood carving, boat making, stone cutting, trading, mat making, tour guiding and tourist transportation. This knowledge includes both indigenous and modern knowledge. The knowledge was acquired from relatives (grandparents, parents) and from others (friends, neighbours) and a few from self-initiative particularly in business and tourist service provision. In families, the knowledge was passed by working together with the children and oral tradition while among others, knowledge was passed through training on the job, training in seminars, field days, sharing of ideas and meetings. Self-initiative involved learning the foreign languages, or undertaking training on tourism packages or business skills from government organizations, non-governmental organizations or colleges.

The fisheries department is in the process of introducing fish farming to avoid destruction of mangroves and fish breeding sites. The activity is in its infancy and has not been widely adopted by the communities.

Trend in availability of natural resources

Respondents expressed their perceptions on the use trend of resource availability (Table 15.4). Over 50 % indicated an increasing trend in use. Some respondents were not aware of any changes. Various reasons were perceived to be the cause of the change in use trend. These included population increase, increased demand for various products (like farm produce, fish, carvings, building materials), low fish populations, increased competition, low tourist numbers, foreign fishermen invading Kenyan waters, increased use of trawlers, increased adoption of modern farming methods, decreased supply of carving wood and its size, destruction of fish breeding sites, deforestation, unsustainable harvest of resources (continuous use without replenishing), decline of income, increased trading and as a source of livelihood. A few respondents did not know why the changes were taking place. It has been reported that population pressure, industrial and tourism development place heavy demands on coastal habitats and ecological resources. More often this leads to natural resources depletion, environmental degradation and conflicts over the use of these scarce resources (UNEP, 1998).

Table 15.4. Perceived trend in availability of natural resources by respondents

Trend of use of natural resources	Per cent respondents (%)
Increasing	54
Decreasing	40
Constant/ No changes observed	6
Total	100

Management of natural resources

The respondents had different perceptions in their role to manage the natural resources. Various groups interviewed enumerated their roles. These included tree planting, conservation and protection of soils and forests, controlled use of resources (such as forest products, mangrove forests and fishing), beach cleaning, education and increasing awareness about natural resource use and management. A few respondents did not see their role in management of resources while some expressed the need for the Government of Kenya to intervene in the management of coastal resources. However, different groups (men, women, youth and various institutions and groups) played key roles in different activities in the communities. The Institutions included Kenya Wildlife Services (KWS), Forest Department, Fisheries Department, and organized groups such as Beach Management Units (BMU), Beach Associations, Coast Tourist Guides Association (CTGA), fishermen groups, self-help groups, Mangrove Forest Harvesters Association (MFHA) and Coast Farmers Forest Association (CFFA). It was evident that there was increasing trend in group organization to assist in resource utilization and management for sustainability.

Natural Resource (NR) management knowledge

Mechanisms of passing on NR knowledge

Eighty four per cent of the respondents perceived that there were mechanisms of passing on knowledge within the communities. Fifteen per cent did not think that there were mechanisms of passing on knowledge while 1 % of the respondents did not know. Several ways of passing on knowledge were enumerated (Table 15.5). Passing on of knowledge through organizations is a new phenomenon as the communities position themselves to offer service to the tourism industry and to utilize resources in a sustainable way with less conflicts arising.

Table 15.5. Strategies used in the community to pass on NR knowledge

Strategies used for passing on NR knowledge	**Per cent respondents (%)**
Through group organizations	15
Oral tradition	15
Training (formal)	5
Working together/training on the job	43
Others (sharing ideas/ no organized mechanism)	6
No suggestion	16
Total	**100 %**

Mechanism for managing the NR knowledge

Seventy four per cent of the respondents perceived that there were mechanisms of managing NR knowledge within the communities. Twenty five per cent did not think that there were mechanisms of managing NR knowledge while 1 % of the respondents did not know. Several ways of managing NR knowledge were enumerated (Table 15.6). Management of knowledge through group organizations such as associations, unions and self-help groups were given weight by the respondents as this is the methodology seemingly being adopted to position the communities as they focus on offering services to the tourism and visiting industry. UNEP in 1998 reported that there is a shift from trade-oriented focus to service oriented activities focused on the tourism and visiting industry at the Kenya Coast. From Table 15.6, it is evident that oral tradition/narration is very low, implying this informal way of disseminating knowledge is no longer popular.

Table 15.6. Management strategies of NR knowledge (161 respondents)

Strategies of managing NR knowledge	Per cent respondents (%)
Training through group organizations	54
Oral tradition	20
Others (no suggestions/did not know)	26
Total	100

Lessons in disseminating NR knowledge

Forty two per cent of the respondents passed on NR knowledge to relatives (children and brothers), fifty three per cent passed on NR knowledge to others (friends and neighbours) and the rest (5 %) did not pass the knowledge or were still learning. Sixty four per cent passed on the knowledge through training on the job/working together while 19 % used oral tradition and the rest used various ways such as training in groups, field days and societies. About fifty per cent of the respondents did not have any problem in passing NR knowledge. However, the rest experienced some difficulties due to lack of interest from the youth, youth preferred modern technology, some form of negative attitude among the youth towards some occupations, children engaged in formal school education and therefore not available to learn traditions, low literacy levels, refusal to take instructions and lack of interest.

The study revealed that oral narration is no longer popular and that parents preferred passing on the knowledge to non-family members. This could be because children are in school and parents have less time to talk and pass on NR knowledge. In addition, western influence from school and the mass media has helped children develop a mind set for white-collar jobs. Hence the lack of interest displayed among some youth.

Lessons in preservation of NR Knowledge

Fifty six per cent of the respondents did not see the need of preserving Indigenous Knowledge (IK) while 42 % did think that IK should be preserved and 2 % did not know. Ninety one per cent respondents perceived NR knowledge to be important while the rest did not see its importance. Sixty one per cent of the respondents agreed that NR knowledge was not documented while the rest 39 % thought that the NR knowledge was documented in one form or another such as brochures and business books. Several ways of preserving natural resources were suggested (Table 15.7). The study revealed that there existed no formalized way of preserving the knowledge. However, modern technology was preferred to the indigenous knowledge.

Others included suggestions to preserve traditional seeds and equipment, teach foreign languages in colleges and provision of market sites for products, particularly crafts, farm produce and other goods.

Table 15.7. Suggested ways of preserving NR knowledge

Suggested ways of preserving NR knowledge	Per cent respondents (%)
Documentation	48
Training the youth	32
Others	8
No suggestions	12
Total	100

Knowledge and knowledge dissemination among farmers

Knowledge acquisition

Among the respondents interviewed in this study, 40 were farmers. Their age range was 23 – 99 years with an average of 44 years. Seventy per cent of the farmers were over the age of 35 years. The farm sizes varied from 0.25 to 45 acres with an average of 9 acres. Unfortunately, 97 % did not hold title deeds for their land. They cultivated a range of crops which include maize, cow peas, cassava, sweet potatoes, rice, green grams, pigeon peas and bananas as food crops while coconut, mangoes, cashew nuts, citrus and mangrove were grown for cash income. Slightly over 50 % of the farmers were also livestock keepers. They kept a range of animals such as cows, goats, sheep, chicken, guinea fowls, ducks and bees. About 50 % of the farmers used indigenous knowledge, which involved use of traditional seeds, hand hoes, broadcasting seeds and keeping indigenous animals. Farmers acquired knowledge through various means as shown in Table 15.8. Although only 15 % represented the female farmers, this is a natural resource that is commonly exploited by women. However, the women are generally not considered as owners of the land and therefore not the bona fide farmers.

Table 15.8. Sources of knowledge for farmers in the coastal areas of Kenya (40 respondents

Source of knowledge	Per cent respondents (%)
Parents/relatives	75
Extension service (Government of Kenya)	10
Others (farmers/ schools/colleges)	15
Total	100

Knowledge dissemination

From the study, farmers were able to disseminate knowledge to their relatives; other farmers/ neighbors while a few did not have an opportunity to do so (Table 15.9). They disseminated knowledge in various ways (Table 15.10). Seventy per cent of the farmers were able to disseminate farming knowledge to relatives such as children and brothers by working together on the farms. There is no formal way of passing on this knowledge. In the study, it did not come out clearly what practices are passed on to the relatives/children or others.

Table 15.9. Knowledge dissemination by farmers

Knowledge passed to	Per cent respondents %
Relatives (children/ brothers)	70
Others (farmers/ neighbors/ self-help groups)	23
No one	7
Total	100

Table 15.10. Methods used to pass on knowledge to others

Method used	Per cent respondents (%)
Working together in the farms	83
Oral tradition	5
Training	5
Did not pass the knowledge	7
Total	100

Knowledge preservation

The study revealed that there is no mechanism used for preserving farming knowledge. Eighty five per cent of the farmers affirmed that the farming knowledge is not documented. In many cases, children/relatives/other farmers observe and copy what the parents/farmer leaders are doing. They suggested that documentation (50 %), training (30 %) and involving children (10 %) should be adopted as a means of preserving farming knowledge.

Knowledge and knowledge dissemination among fishermen

Knowledge acquisition

Among the respondents interviewed in this study, 34 were fishermen. Their age range was 17–67 years with an average of 36 years. About 60 % per cent were within the age group of 17-35 yrs. Their fishing experience varied from 2 to 55 years with an average of 18 years. Most of them went fishing within the beaches in their respective districts. These included Lamu, Malindi, Kipini, Msambweni, Kwale and a few went deep-sea fishing. The species harvested included parrotfish, sharks, kingfish, snappers, catfish, lobsters, prawns and crabs. Most of the fishermen were artisan fishermen using canoes/boats and fish traps made from reeds/raphia and nets. About

50 % fishermen used indigenous knowledge (IK), 30 % used both IK and modern technology while the rest 20 % used modern techniques in fishing. This is a male dominated activity with 100 % respondents being male. The fishermen acquired knowledge through various means as shown in Table 15.11.

Table 15.11. Sources of knowledge for fishermen in the coastal areas of Kenya (34 respondents)

Source of knowledge	**Per cent respondents (%)**
Parents/relatives	44
Others (friends/ older fishermen)	56
Total	100

Knowledge dissemination

From the study, fishermen were able to disseminate knowledge to their relatives; other fishermen/friends while a few did not have the opportunity to do so (Table 15.12). They disseminated knowledge in various ways (Table 15.13). Ninety per cent of the fishermen were able to disseminate fishing knowledge to relatives and others. There is no formal way of disseminating this knowledge. In the study, it did not come out clearly what practices are passed on to the children/relatives.

Table 15.12. Knowledge dissemination by fishermen

Knowledge passed to	**Per cent respondents %**
Relatives (children/ brothers)	33
Others (fishermen/ neighbors/ friends)	60
Still learning	9
Total	100

Table 15.13. Methods used pass on knowledge to others

Method used	**Per cent respondents (%)**
Training on the job	90
No way of passing knowledge	10
Total	100

Knowledge dissemination

The study revealed that, craftsmen/women were able to disseminate knowledge to their relatives; other craftsmen/ friends while others were still learning (Table 15.14). They disseminated knowledge in various ways (Table 15.15). Ninety per cent of the craftsmen/women were able to disseminate knowledge on handicrafts to relatives and others. There is no formal way of passing on this knowledge. In the study, it did not come out clearly what practices are passed on to the children/relatives.

Table 15.14. Sources of knowledge for craftsmen/women in the coastal areas of Kenya (30 respondents)

Source of knowledge	Per cent respondents (%)
Parents/relatives	43
Others (friends/ older fishermen)	53
School	4
Total	100

Table 15.15. Knowledge dissemination by craftsmen/women

Knowledge passed to	Per cent respondents %
Relatives (children/ brothers)	55
Others (craftsmen/ neighbors/ friends)	44
Still learning	1
Total	100

Knowledge preservation

The study revealed that there is no mechanism used for preserving handicraft knowledge. Whereas 73 % indicated that there was a place for indigenous knowledge, 97 % thought that it was important to preserve handicraft knowledge. About eighty five per cent craftsmen affirmed that handicraft knowledge is not documented. In many cases, children/ relatives/ other craftsmen learn by observing and practicing with others and with time, gain experience. Children in formal school are not available for such an activity and it is possible for them not to learn this kind of craft. The craftsmen suggested that documentation (40 %) and training (43 %), archiving of information (3 %) could be adopted as a means of preserving handicraft knowledge. The rest (14 %) did not have any suggestions. They perceived the future as being bleak for this activity because wood supplies were declining, sales were declining, and that marketing was a problem.

To address the marketing problem they formed a co-operative society to enable them access market in bulk.

Knowledge and knowledge dissemination among business men/women

Knowledge acquisition

Among the respondents interviewed in this study, 28 were involved in various businesses related to the natural resources within the coastal area. Fifteen per cent of these were females. Their age range was 19 – 65 years with an average of 37 years. About 60 % were within the age group 19-35 years. Their business experience varied from 1 to 40 years with an average of 10 years. The kinds of businesses included fish trading (43 %), fruit and vegetable selling (14 %), tree nursery men (11 %), wood carving (11 %), bead work sellers (7 %), hard wood trading (4 %), building stone dealers (4 %), coral stone dealers (4 %) and mangrove pole dealers (4 %). About 55 % businessmen used indigenous knowledge, 20 % used both IK and modern technology, 15 % used modern techniques and the rest 10 % were not sure where to place the knowledge they used. The craftsmen/women acquired knowledge through various means as shown in Table 15.16. This is an activity where women exploit natural resources to derive their livelihood.

Table 15.16. Methods used to pass on knowledge to others

Method used	**Per cent respondents (%)**
Training on the job	73
Oral tradition	17
No way of passing knowledge	10
Total	100

Knowledge dissemination

From the study, businessmen were able to disseminate knowledge to their relatives; other businessmen/ friends while a few did not see any need to do so (Table 15.17). They disseminated knowledge in various ways (Table 15.18). Ninety five per cent of the businessmen were able to disseminate business knowledge to relatives and others. There is no formal way of passing on this knowledge. In the study, it did not come out clearly what skills are disseminated to the children/relatives.

Table 15.17. Methods used to acquire knowledge

Source of knowledge	Per cent respondents (%)
Parents/relatives	32
Others (friends/ older businessmen)	45
College and self initiative	16
NGOs / institutions	7
Total	100

Table 15.18. Knowledge dissemination by businessmen

Knowledge passed to	**Per cent respondents %**
Relatives (children/ brothers)	20
Others (neighbors/ friends)	75
No need of passing knowledge	5
Total	100

Knowledge preservation

The study revealed that there is no mechanism used for preserving business knowledge except in textbooks. Ninety four per cent indicated that there was a place for indigenous knowledge and all of them indicated that it was important to preserve business knowledge. About eighty per cent businessmen affirmed that business knowledge is not documented. In many cases, children/relatives/other businessmen learn by practicing in their parents/friends premises until they gain experience. Children in formal school are not available for such an activity and it is possible for them not to learn about the business. The businessmen suggested that documentation (43 %) and training (36 %) could be adopted as a means of preserving business knowledge.

Knowledge and knowledge dissemination among tourist industry service providers

Knowledge acquisition

Among the respondents interviewed in this study, 29 were tourist industry service providers. Their age range was 25– 56 years with an average of 37 years. About 65 % per cent were within the group, 25-45 years. Their service experience varied from 5 to 38 years with an average of 16 years. They offered various services, which included tour guiding (70 %) tourist transportation, boat operating and safari selling. About 30 % of these service providers used indigenous knowledge (IK), 56 % used both IK and modern technology while the rest 14 % used modern techniques. This is a male dominated activity with 100 % respondents being male.

Knowledge dissemination

From the study, tourist service providers were able to disseminate knowledge to their relatives; friends while a few did not have opportunity to do so (Table 15.19). They disseminated knowledge in various ways (Table 15.20). Ninety per cent were able to disseminate knowledge to relatives and others. There is no formal way of passing on this knowledge. In the study, it was not clear what practices are disseminated.

Table 15.19. Methods used to pass on knowledge to others

Method used	**Per cent respondents (%)**
Training on the job	50
Oral tradition	25
Field days/ in groups	20
N/A (Those who did not pass the knowledge)	5
Total	100

Table 15.20. Knowledge dissemination by businessmen/women

Knowledge passed to	**Per cent respondents %**
Relatives (brothers)	7
Others (friends)	93
Total	100

Knowledge preservation

The study revealed that there is no mechanism used for preserving tourism service provision knowledge. All indicated that there was a place for indigenous knowledge and that it was important to preserve tourism service provision knowledge. Forty per cent affirmed that tourism service provision knowledge is not documented while 60 % indicated that it was documented in other ways such as in brochures. In many cases, friends and relatives learnt by practicing until they gained experience. Children in formal school are not available for such an activity and it is possible for them not to learn about this knowledge. There were however, reported cases of children dropping out of school to find their livelihood in the tourism industry service provision activities. Tourism service providers suggested that documentation (56 %) and training (40 %) should be adopted, as a means of preserving fishing knowledge. The rest (4 %) did not have any suggestions.

Discussion

The coastal belt where this study was carried out covers an area of about 89,370 km^2. The area has very poor road network and public transport. It is difficult to move from one point to another. The area had some very old trees (mango, coconut and cashew nuts) planted during the rule of the Sultan of Oman. The locals do not own the land and the area is a net importer of almost all foodstuffs despite having 70,000 ha of land with irrigation potential. Farmers in most areas, particularly in Malindi division are squatters. The land still belongs to the absentee landlords, the Arabs, who went back to Oman when the Sultan rule came to an end.

The study results seem to point at the fact that people/communities tend to concentrate and are more aware of the natural resources that they use. They are not aware of other natural resources available in the area. For example, a few respondents mentioned minerals as a natural resource yet they did not mention salt, limestone or iron. A high percentage of people on the coastal strip depend on marine resources (Ocean) including mangroves as evidenced by the manner in which they enumerated such resources.

Knowledge flow tended therefore to be confined to the stakeholders. For example those in tourist industry service provision talked about the services they offer and how they have formed Beach Management Units. In the Units they have been organized into groups that operate in shifts to serve and clean the beaches. Similarly the wood carvers spoke of the Coast Farmers Forest Association, which subscribes to Forest Stewardship Council worldwide. The council deals with forest certification against ISO standard 14000. This is all about sustainable forest management. The wood carvers have to make sure that the source of their wood supply is managed in a sustainable manner and that the product can be traced back to the farmer who produced the wood. As a result they have been forced to have management structures for the farm (s). Currently, they have been given 300 acres to plant neem for sustainable use of the trees for carving purposes particularly for export goods as they adopt good wood practices. The mangrove users have also formed their association to enable them utilize the resource in a sustainable way while they replenish by planting more mangroves. The Fisheries department of the government of Kenya is also encouraging fishermen to form groups to control fishing activities, marketing and protect fish breeding sites, thereby utilizing the resource with fewer conflicts and in a sustainable manner.

Knowledge flow has largely depended on individual initiatives. It is only recently that efforts were made to get communities together for better utilization and management of resources. This is more vivid with the marine resources. There are the Beach Management Units and the Coast Tour Guide Association with branches in each district. Farmers are beginning to get together in some areas assisted by the agricultural Officers and Research staff for purposes of learning more technologies and support for adoption. There is a lot of influence from the upcountry ethnic groups that are settling in the area. One Akamba and a Waldei farmer found in the area during the interviews particularly impressed the interviewers. The Walde, a traditional herdsman had successfully learned from the Akamba tribesman who had come to the area with farming knowledge from the hinterland and both of them were demonstration farmers for the Ministry of Agriculture extension staff in the Division. The two were successfully growing maize, cotton, bananas and legumes. Mangrove forest harvesters are getting together in Lamu under the Mangrove Forest Harvesters Association. The carvers in Malindi and Mombasa have their Co-operative Society and an Association to enable them access acceptable wood and market for their products. The craftsmen/women particularly those who weave in Kipini and Kilifi were making efforts to come together but have not yet succeeded.

No specific systems were identified for acquiring, disseminating, preserving and managing natural resource knowledge. The knowledge is not documented and will not be available to the younger generation once the older one passes on. Unfortunately the youth have very little interest in this knowledge. The school going age is not available because they spend most of the time in school.

Gender inequality in the utilization of natural resource management was evident. Men dominated all activities undertaken as livelihood options in the area. Women were only represented in business trade, handicraft work and in farming.

Findings In Tanzania

Characterization of the communities

In the case of Tanzania, male respondents were many (68 %) as opposed to female respondents (32 %). The reasons for most of the respondents being male may be partly explained by the division of labour among them. For instance, fishing, crafting, crab farming, tour guiding, and traditional healing activities were mainly performed by men though in some cases even women were involved for example in weaving, drying, frying and selling fish and in agriculture. The results indicate further that majority of the respondents (85.2 %) were married, widowed (11.1 %) and 3.7 % were single. The larger percentage of married respondents (85.2 %) may be a reflection of maturity and traditions that seem to encourage early marriages just after completion of primary education.

In terms of level of education, the majority of respondents (70.4 %) had primary education, 22.2 % had formal education and only 7.4 % had secondary education. The tendency of neglecting education in favour of fishing and early marriages was found to be a typical characteristic if not a culture of coastal communities. Also preference on Qoranic School "*madrasa"* by Moslems over primary education may have contributed to the low education among the coastal communities.

Generally, it was found that Moslems dominated the respondents across the study areas. Findings of the study indicated that 86.2 % of all respondents were Moslems, 10.3 % were Christian and 3.4 % represented respondents who did not communicate their religion and atheists. The reason for the Moslems being dominant may partly be explained by the Arabs who brought this religion and settled first in coastal areas before penetrating into the mainland.

Majority of the respondents along the coast were engaged in fishing and crafting of various items as their socio-economic activities contributing to their livelihoods. Socio-economic activities identified in the study areas include farming, salt-making, tourism, and farming, fish-farming, and petty trading. Most of coastal people are engaged in exploitation of marine and land resources while few of them are subsistence farmers and charcoal burners. As advocated by van Ingen *et al.* (2002), fishing activities were found to be the most dominant activity for the majority of the people living along the coast.

Natural resources available and uses

Natural resources available

The study identified numerous natural resources along the coastal areas that are used by coastal people in improving their livelihood thereby reducing poverty. These resources were categorized into two major groups, i.e. marine and land resources. Marine resources that were identified include fish, mangrove forest, islands, crabs, prawns and shrimps, coral reefs ("Matumbawe"), turtles, sea-shells, squids and octopus, seaweeds, sea cucumber and seawater (salt). Land resources mainly consisted of mangroves, raphia, land, gravel, sand, river and river basin wetlands and terrestrial plants. These findings are supported by the study of Horrill *et al.* (2001), who documented similar findings when conducting a study on collaborative reef and reef fisheries management in Tanga, Tanzania.

Palms are very common in the wetlands of the Pangani river basin especially in the lowlands and coastal areas. The most common are Lala palms, Hyphaene spp (locally known as *mikoche/miaa/minyaa*). These palms grow at sea level and inland along seasonal water courses and often found at the edge of springs and floodplains. Also another common wild date palm leaves, *Phoenix reclinata* (locally known as *ukindu*) occur in the warm lowlands and coastal areas usually besides swamps and rivers. In addition coconut palms, Cocos *nucifera* (*minazi*) are typical along the lowlands and coastal areas.

Uses of natural resources

The results indicated that people living along the coast have accumulated a lot of knowledge on utilization of natural resources for their livelihood improvement. Fish was also used mainly as source of income among the coastal communities.

In order to be a successful fisherman, one has to know the different species of fish, their ecological conditions, their movements categorized by diurnal and seasonal changes as well as movement of water and winds to facilitate ease of transport capture and aversion of risks. None of this knowledge is documented, but each experienced fisherman seemed to know exactly where to go for what fish, when and even an element of probability of success. Fishermen also listen to the sounds of the sea in order to determine the direction and sources of danger, such as tidal waves. Their navigational acuity is gained through experience, making it possible for them to spend many hours at sea and return home safely without any modern navigational equipment.

The dishes cooked depend on the type of fish. This area is generally managed by women. By knowing the different species of fish, the women are able to determine exactly what other food ingredients (cereal, vegetable and spices) go well with them. This knowledge is extremely valuable and should be captured by food and nutrition experts for wide dissemination.

Mangroves forest are both marine and land resources that are associated with lagoons and estuaries and communities recognize that they are important habitats for aquatic organisms and do regulate ecological integrity along the seashores. The results of the study also indicated that coastal people use mangrove resources to supply local community needs for example fuel wood, charcoal, fences, poles for house construction, boat building, fish trap-making, fishing stakes and medicines. Similar findings were reported by Anon (1998); Horrill (2001) and Ngaga, *et al.* (2005). Also mangroves forests are used along the coast in installing beehives.

Coconut palms have found many uses among coastal communities, the main products being coconuts and palm leaves as thatching material for roofs and fences. After extraction of the coconut oil, coconut shells (*vifuu*) have been used for making utensils and ornaments for many years. The utensils produced include bowl (*bakuli)*, scoop (*kata*), shallow ladle (*pawa*) and cups for domestic use. Ornamental items like rings, key holders, office containers, ear-rings and hair holders, are made and used widely in many places.

Coconut husks are also very useful as they are used in making fibres used in the production of carpets and ropes used in boat rigging, binding of fish traps and baskets. Coconut husks are first buried along the seashore for about six months to soften husks and make extraction of fibres easy. Currently, a lot of women groups along the coast in Tanga and Pangani are involved in using the material to produce those items.

When coconuts have dried (*mbata*) to the extent that is not suitable to extract coconut oil for food, it is used to produce another type of coconut oil traditionally used by people as body oil and for cooking rice bran (*vitumbua)* for many years. Production of this type of oil is done by two methods: boiling coconut extracts and pressing giddiness slices. Both methods are indigenous and current producers have learnt from their mothers and grandmothers. The technology has not been developed beyond the traditional equipment.

On the other hand craftswomen have accumulated a lot of knowledge on using hyphaene/raphia) to make various items such as brooms, baskets, *milala* mats (*vitanga*), drying mats (*majamvi*). Furthermore, Phoenix (*ukindu*) is used mainly by women to make *ukindu* mats (*mikeka*), praying mats (*miswala*), covers (*kawa*), fans (*vipepeo*), sleeping bags, hats, ropes and many other uses. Phoenix leaves can also be dyed to produce colourful mats. The craftswomen have enormous skills which through technological improvements could leverage their production levels and raise quality to make the mat industry stronger and able to export products.

Findings from field visits indicated that some fishermen use islands as camping sites. Sometimes these attractive islands were reported to be used as recreational sites by tourists. Marine resources such as crabs, shrimps, prawns and sea cucumber were exploited locally and the surplus exported to other countries such as China and Europe which bring in foreign exchange. Seaweed that was found cultivated by some coastal communities is used as cash crop. According to the study by Maghimbi (1997), other uses of seaweed crops include making preservatives and medicines. In the study areas, terrestrial fossil, coral rock and even mollusc shells were used as a source of calcium carbonate and are baked in kilns for the production of lime. Seawater that contains approximately 3.5 % salt is used as raw material for salt production by evaporation. Basically, this constitutes an open fire system heating a metallic evaporation pan filled with salty water.

Users of natural resources

The results indicated that there is no gender equality on the uses of natural resources along the coast. About 86 % of the respondents interviewed acknowledged that most users of the coastal resources are men, dominating potential activities such as fishing, collection of sea cucumbers, crabs, prawns, shrimps, squids and octopus, crab farming, charcoal production, and coconut harvesting and processing. Women were actively involved in exploitation of raphia mats, baskets, broom making and related items. However, findings indicated that some natural resources were used by both men and women. These natural resources include land for agriculture and livestock keeping, mangrove forests, seawater, seaweed and seashells collection.

Knowledge on natural resources

The results showed that coastal communities have potential knowledge on some of the available resources and their uses. This knowledge includes fishing, fish processing and selling, handicrafts, salt making, alcohol processing from palm trees, cutting and using mangroves, agriculture and animal keeping inherited from their grandparents. The source of the knowledge is from interaction within families, between families, across members of the community and with foreign visitors many years ago.

The results from key informants in some places showed that the knowledge on fish farming, crustacean (crab, shrimps and prawns) farming, seaweed farming were acquired through seminars and study tours. The results revealed further that fish-farming knowledge was acquired in the early 2000s through study tours. For instance, VUMILIA fish farming group in Machuwi village, in Tanga region, Tanzania started the activity in November 2005. Fish farming included fish species such as *Chache, Nduka, Kamba* and *Tanda*. Crustacean and crab farming for example was identified to be practiced under mangrove forests by the WAKAPA group in Pangani district. This project was reported to have started in 2006. One of the earliest crustacean projects in the Western Indian Ocean was financed by FAO near Malindi, Kenya in 1992 (Richmond, 1997).

Furthermore, the results showed that seaweed farming is a new income generation activity among the coastal communities in the study areas especially in coastal areas of Tanzania mainland contrary to Zanzibar where the knowledge is reported to have started way back in 1989. It was found that the most grown seaweed *(Eucheuma)* species includes *E. denticulatum* and *E. cottoni.* Currently, seaweed is regarded as supplementary cash crop, in addition to coconuts and cashew nuts. In addition, seaweeds are regarded as an additional livelihood strategy to fishing in many coastal communities, particularly in Zanzibar, Tanga, Muheza, Pangani, Bagamoyo, Mtwara and Lindi. Another study conducted by Mgaya (2000) noted that seaweed is an outstanding cash crop for improving the livelihoods of communities along the Indian Ocean.

Trend in the availability of resources

According to the respondents, 88 % of them were of the opinion that availability of natural resources indicates a decreasing trend. This is probably attributed to population growth, unsustainable harvesting of resources, natural disasters like Tsunami and El Nino and increased trade. The growth of population increases pressure on the resource utilization. Nearly 75 % of the respondents indicated that, mangrove forests are highly affected by this phenomenon where most of the forest is cleared. It was estimated that, sea salt producers deforested about 350 ha of mangrove forest in Chongolean village, Tanga, Tanzania (Balastis Mfwima, Pers. Communication). Also illegal trade of mangrove poles to Asian countries is not uncommon and depletes most of these resources (Mgaya, 2000). Unsustainable harvesting of the natural resources like the use of dynamite, small mesh size (about 0.5 inch) nets (kokolo) and poisons destroy breeding grounds of fish as well as depleting the resources (IUCN, 1993; Gorman, 1995). The potential for charcoal market in Zanzibar has also increased the rate of charcoal production in Kipumbwi village, Pangani district, Tanzania.

Management of natural resources

Communities living along the coast play significant roles on management of coastal resources. For instance, the study identified that most Village governments (seven out of 10 villages visited) have formulated Village Environmental Committees (VECs) in some of the study areas. It was reported further that, the main responsibility of these village environmental committees is to conserve natural resources in their respective villages. For example in Chongolean village in Tanga region, Tanzania about 6,757,150 mangrove tree seedlings were reported to have been planted on 350 hectares. In some areas, these VECs have achieved remarkable success in the management of marine resources particularly mangroves forests. Also most of the communities are aware that some of these resources are protected by sectoral laws and/or regulations.

Natural resource management knowledge

Mechanism for managing and passing on knowledge

It was found that there was no institutionalized mechanism of managing NR knowledge among communities. There exists an informal mechanism of managing the natural resource knowledge along the coast through parents/elders interacting with children. The findings of the study indicate 55 % pass on knowledge through working together with family and/or community members (Table 15.21). Some parents, as reflected by 16 % of the respondents pass knowledge through oral traditions and counsel their children on various issues related to natural resources and their impacts on their livelihood. For instance children are advised not to cut small mangrove trees. Also parents use oral tradition in transferring knowledge on natural resource management to their children. Children are encouraged to report to the respective organs and/or parents, all issues concerning natural resource degradation or if they see people doing illegal activities. According to the respondents, the habit of counseling children and within community members had deteriorated among parents because of various socio-economic changes and settings. Also 10 % of the respondents indicated that training and writing is used as another way of passing on knowledge. There are some efforts to incorporate some elements of natural resource management in the primary school curriculum for standard V-VII. For instance, in Tanga region-Tanzania, the primary school curriculum with natural resource management was reported to have started in 1998 and operates in 30 primary schools.

Lessons in passing on NRM knowledge

It was found that only a few parents (16% of the respondents) talk with their children on NRM knowledge. Therefore, the traditional methods of passing natural resource management knowledge to the young generation are slowly deteriorating. This is due to the nature of activities that are performed by parents. For instance, many parents spend most of their time in production activities, for example fishing. Parents have less time to stay with children to talk and pass on NRM knowledge to them partly because the latter spend most of their time in schools and therefore they do not have practice in the specific skill areas. Also the introduction of western oriented cultures is also seen as barrier towards transfer of indigenous knowledge to the young generation. Most youths spend most of their teenager time learning about different cultural aspects in formal education schools. It was found further that, after completion of their primary education, many youths adopt new life style that is euro-centric neglecting traditional culture. According to the respondents, the wide spread of sophisticated technology such as TVs, radios, computers and internet programmes, play a big role in defining the interest of youths.

Lessons in preservation of NRM knowledge

The study revealed that there is no proper or formalized mechanism of preserving NRM knowledge among the coastal communities. Seventy five per cent of the respondents indicated that the knowledge is not preserved and 38% noted that it is important to preserve. About 47% of the respondents did not see the need for preserving the knowledge. The possibility of knowledge deterioration is obvious since most youths do not show keen interest on local knowledge capture, collation and application. For example while in Chongoleani village in Tanga region Tanzania, it was found that an old man who has been working in crafts industries making dhow for about 45 years has managed to teach only two young men out of many he tried to recruit. The main reasons include the fact that the work is tedious; takes a long time to complete one dhow because of inferior tools used and the demand is seasonal/irregular. Under these circumstances, there is a tendency for youths to shy away from such traditional activities which are labour demanding and not fast paying.

Knowledge and knowledge dissemination among farmers

Knowledge acquisition

Thirty farmers were interviewed and their age ranged from 25 to 61 years with an average of 45 years. According to the survey results, 80% of the farmers interviewed acquired farming knowledge from their grandparents and/or parents. During the study 92% of the farmers interviewed noted that, they acquired the farming knowledge through going together with parents/grandfathers/mothers to the farms while eight per cent have acquired through seminars. Most parents taught their children how to cultivate and tend to crops. They work together in farm activities by giving them a portion of land to work on using small hand hoes. It was observed that most children of about 10 years old from a family of farmers were already equipped with farming knowledge. It was reported that girls were participating actively and effectively in weeding farms during weekends and holidays. Knowledge is predominantly tacit or embedded in the practices and experiences (Ulluwishewa, 1997). Further, it was found that 95% of the farmers interviewed are still using hand hoes and they're few who solely rely on it for a living. As reported by Scoones and Thomson (1994), coastal communities began farming activities many years ago. They own pieces of land of about 2 ha with perennial plants like coconuts, cashew nuts and fruit trees. The most common crops grown include maize, millet, rice, sweet potatoes, and cow peas (van Ingen *et al.,* 2002). In some households, women do farm activities while their men are fishing. Also coastal communities were found to engage in livestock keeping, especially sheep, cows, goats and poultry. The number of livestock varies depending on the wealth status of the livestock keeper/farmer.

Crustacean farming, especially crab farming is a new technology recently started among coastal communities. Formerly, coastal people were naturally collecting crabs for food and export. The technology of fattening crabs in order to satisfy market requirements started in May 2006 in Pangani district. Those practicing crab farming have constructed crab's cage under mangrove forests and usually provide them with food. It was reported by the group that this knowledge of crab farming was acquired through seminars, and it was motivated by those who for quite sometime were engaged in collecting crabs for exports.

Coconut trees are also a potential crop for the economy of most coastal communities. In addition to its fruits, coconuts provide famous beverages (Pombe ya mnazi-mdafu). The extraction of alcohol from coconuts started many years ago. All the five extractors, "Wagemaji" interviewed learnt from their grandparents. According to the extractors, normally extraction is done twice a day, early morning and late evening by cutting a flower bud and tying a gourd, *"Kibuyu"*. The alcohol is collected in a gourd poured in a plastic container and ready for marketing. The activity is mainly done by men although selling in pombe shops/clubs is often done by women. The key areas of improvement include sanitation and preservation of the beverage. Currently the beverage lasts only 2-3 days, beyond which it ferments into unusable state.

Seaweed farming in coastal communities is also a new knowledge adapted from field studies, visits and seminars. It was found that some communities in coastal areas began seaweed farming in 1994 through on farm training *(Shamba darasa)* (van Ingen *et al.,* 2002). The crop is grown on seashore with gentle slope and the crop is harvested on average after every 2 months. Farmers involved their children in most of the activities like tying pieces of ropes (taitai) in the main rope, planting, harvesting and drying of seaweed. During weekends children were taken to the field to participate in seaweed strips cleaning. In this way they acquire some seaweed farming knowledge.

Knowledge dissemination

The findings of this study indicate that there is no formal mechanism of disseminating agricultural knowledge to community members or to the children. According to the respondents interviewed, farming is commonly disseminated through seeing, personal communication and demonstration (8%); from master to apprentice (3%), from parents to children (80%), from neighbor to neighbor (9%) (Table 15.21). For instance, the number of seaweed farmers was increasing because early adopters disseminated the technology to other members of the coastal community. In Ushongo village for instance, the number of farmers has increased from 32 in 1994 to about 90 farmers in 2006.

Table 15.21. Strategies used in the community to pass on NR knowledge

Strategies used for passing on NR knowledge	**No. of Respondents, N**	**Per cent respondents, (%)**
Oral tradition	13	16
Training (formal) and writing	8	10
Working together/training on the job	44	55
Through friends	2	3
None	13	16
Total	80	100

The study noted that very few people (only six per cent of interviewed farmers) along the coast have adopted crab farming when compared to agriculture and seaweed farming, especially the youth. This is probably due to the fact that the type of farming requires high investment cost including food storage facilities, construction costs, and other running costs. For example, the WAKAPA Group (Wafugaji Kaa Pangani) run by 10 male members invested about Tsh. 1,540,000/= to run a project of 1000 crabs something which is difficult for youths who do not have the capital or a reliable source of income.

Knowledge preservation

The study noted that there was no proper mechanism of preserving farming knowledge in the study areas. About 95% of interviewed farmers do not document the knowledge they have, of performing/conducting/doing their activities. Normally farmers work through experience and inherited procedures from their ancestors. Their children as well have been adopting what they see and learn from their parents.

Knowledge and knowledge dissemination among fishermen

Knowledge acquisition

Findings from the 30 fishermen respondents indicated that 80% of them have been learning about fishing techniques from their parents and brothers during their childhood. It was reported that some of the fishermen started fishing by using hooks along the shoreline together with other knowledgeable children. The study showed further that fishermen learnt about fishing in the deep sea by travelling with the parents using canoe or dhow. In Kunduchi village in Dar es Salaam, one old man (76 years) Mr. Halid Athuman reported that he has five boys and all of them are fishermen and that he used to go with them and teach them on how to lay down nets and fishing by hooks. The methods that are used today by coastal communities in the study areas are still traditional with little or no modification at all. The common fishing methods include hooks and lines, nets, and traps. During the study, fish trap fences were not mentioned and researchers did not come across them probably due to the fact that most coastal communities do not have enough capital to privatize the coastal beaches. Fishermen also do diving as a part of fishing activities. Diving is done with spear gun or free hand during collection of octopus and sea cucumber. Diving is a traditional method of fishing and for most was inherited from fathers and grandfathers. Fishing is a typical knowledge area among the communities living along the coast of the Indian Ocean (van Ingen *et al*., 2002; Ngaga *et al*., 2005).

Knowledge dissemination

Discussions with fishermen indicate that 56% of them were disseminating knowledge through teaching their children or young brothers about hook preparation, bait digging, net repairing and putting baits in fish traps *(Madema).* Also about 47% of the respondents indicated that they disseminated knowledge through friends, fishermen and neighbours. During fieldwork, it was found that some fishermen were teaching their children about catching small fish left by high tide with small traps or nets (Mosquito gauze). The knowledge is also disseminated to those who come to live in coastal villages through seeing what fishermen are doing and in that way, different fishing techniques are learnt. All fishermen interviewed said there is no tradition of preparing readable materials about fishing or any of the fishing techniques/means.

Knowledge preservation

Interestingly it was found out that all fishermen interviewed do not preserve the indigenous knowledge of fishing. They feel that it is a common knowledge that any children born by a fisherman will just learn and 70% of them did not see the need for preserving.

Knowledge and knowledge dissemination among craftsmen / women

Knowledge acquisition

Among the respondents interviewed in this study, 15 were craftsmen/women. It was found that 87% of the craftsmen interviewed have acquired knowledge through helping their parents in activities such as weaving, woodworking, traps making and nets repair while two per cent have acquired it through friends. Furthermore, it was found that most of the craftsmen and women were old and they said that they acquired the knowledge from their parents. Their age range was 35 to 76 years with an average of 51 years. Knowledge of making products from coconut palms and leaves was also inherited from parents.

Indeed it was found that both women and men have accumulated a wealth of knowledge on natural resources for their livelihoods and substantial income is generated from these resources. Most of the women who were interviewed said that they had been in the business for many years and some of those interviewed had about 35 years or more in craftwork. It was reported by old women that the number of youths with such knowledge was decreasing since most youths seem not to be interested in traditional activities. For instance, in recent years it has been very difficult for the youth to participate effectively in making "kumba" for fencing and "bale" for thatching (van Ingen *et al.,* 2002). The traditional technology used by coastal communities for hundreds of years is currently in danger due to poor acquisition and the introduction of iron-corrugated sheets used in place of coconut leaves. Also as reported earlier, it was found that 80% of the interviewed fishermen had acquired knowledge of making fish traps *"Madema"* from parents/grandparents or from friends fishing together.

Apart from that, knowledge acquisition among coastal communities through making dugout canoe, *Ngarawa, Jahazi, Mashua, Pirogue, Boutre,* and *Boats* was reported to be very effective. In case of woodworks, the study identified businessmen especially from the Makonde tribe making and selling carvings.

The study found further that, this activity was originally brought in Bagamoyo by the Makonde communities from Mtwara region, Tanzania. However, currently the occupation has attracted the attention of other tribes such as Ndengereko, Zaramo and Kwere apart from the Makonde communities. According to the respondents, 96% of them indicated that tourists are the main customers for the carvings. Nonetheless, in some cases even local customers were buying carvings at reduced prices.

Knowledge dissemination

According to the craftsmen interviewed, 92% of them indicated that dissemination is done through teaching those interested through on-work/job training. The knowledge is accumulated in their heads and has to be disseminated through practice. Most respondents (77%) said that dissemination of knowledge to some of their children and/or youths is facing some problems mainly due to changes in socio-economic settings in villages and globalization. All the youths interviewed said the activity (making carvings) takes long time to finish a single product and the demand of the products is low. There was no guarantee that once you finish there is ready market. Ready-made products from industries also were mentioned by the craftsmen to contribute to shying away of the youths from these activities. Nevertheless, in some few cases the study identified craftswomen making mats together with their children.

Knowledge preservation

It was found that there is no mechanism for preserving craft knowledge. All craftsmen/women respondents do not document this knowledge; it is just in their minds. Moreover, lack of reliable markets caused by small number of tourists' currently visiting remote areas has further discouraged development and efforts to preserve craft knowledge.

Knowledge and knowledge dissemination among people in tourism industry

Knowledge acquisition

Tourism industry is a potential activity to most of young men along the coast. This occupation has somehow tried to solve problems related to youth unemployment. For instance, in Bagomoyo district/town, tour guiding is a prominent activity among the youths. Historically, this activity is believed to have originated as a result of solving problems related to unemployment. Thereafter, tour-guiding activities were institutionalized in Bagamoyo in order to reduce the extent of threats to tourists.

Fifty two per cent of the respondents interviewed said that they acquired tour guiding knowledge from friends. However, about 40% of the respondents have attended some training/seminars on tour guiding though the knowledge is inadequate. Some youths do tour guides to tourists who visit cultural centres and ruins. There are potential cultural tourism attractions along the coastal areas like *ngoma*, marriages, dressing and traditional food preparation and eating. For example, in Bagamoyo, there are a number of tourists attraction centres including historical sites, Saadani National Park, fishing grounds, mangrove forests, turtle parks, Kaole well and Arab ruins. Ushongo and many other ruins and Amboni caves also play a key role as scenes to attract tourists along the coastal areas of Tanga region Tanzania.

In addition the study established that about 20% of the coastal communities interviewed were collecting seashells as ornaments and food. The knowledge on collection and processing was acquired by 60% of the respondents through working together with their parents while 30% acquired that knowledge through friends. The most common seashells collected include tusk shells, top shells, pheasant shells, worm shells, Cab shells, cowries, helmet shells, coral shells, dove shells, vase shells, cone shells. Most youths were engaged in collection and selling of seashells to the tourists.

Knowledge dissemination

Knowledge on tour guide spread fast among youths in coastal areas. For instance in Dunda village, Bagamoyo, Tanzania, this knowledge on tour guides is disseminated to others through written documents (38% of the respondents) while 62% of them learn through working together practically with the experienced ones when guiding the clients (tourists). Youths (of both sex) especially those who can speak English had a better chance of involving themselves in this activity and some of them were found to be in strategically potential areas for tourists hunting for clients during the study.

Knowledge preservation

About 50% of the respondents revealed that the knowledge on tourist industries is preserved through brochures, exercise books and pamphlets.

Knowledge and knowledge dissemination among people in business/trade

Knowledge acquisition

Coastal communities are believed to have acquired trading / business many years ago from the Arabs and other foreigners. The source of this knowledge of trading / business is probably due to this interaction. It was found that 70% of the businesspersons interviewed were involving themselves in trading activities like retail shops and kiosks; supplying the nearby villagers with fish and other essential goods, and food vendors especially in fish camps and fish auction markets. The study found that 40% of the respondents inherited the trading/business knowledge from their parents and grandparents. Nearly 68% of the retailers found were the ones whose parents/brothers or other relatives were businessmen. There were few entrepreneurs of both sexes who engaged in selling fish. Fish for trading were bought in auction markets and sold in streets. In addition, 20% of the respondents engaged in business noted that they were forced to learn business out of family problems and/or unemployment, and ideas came from friends and neighbours, and through visiting fishing camps or auction markets.

Knowledge dissemination

About 60% of the respondents indicated that business knowledge is disseminated across generations by involving youth in daily working. Children especially boys were involved in retail shop and kiosk while their parents engaged in fishing or other activities. On the other hand, about 23% of the fishermen interviewed were accompanied by their children to the fish market. Nevertheless, most of the youth were shying away from fish business because of the difficult and poor working conditions.

Knowledge preservation

All business-persons respondents indicated that there was no mechanism by the business community to preserve the knowledge on business/trade.

Knowledge and knowledge dissemination among traditional healers

Knowledge acquisition

With regard to traditional medicines, the study found that coastal communities have been using coastal plants and marine resources for treating different ailments. Further, 95% of the traditional healers interviewed acquired the knowledge from their grandparents and/or parents while the remaining five per cent acquired the knowledge from the current traditional experts. It was revealed by the traditional healers that most youth failed to follow the conditions during learning processes. A child who needs to be a traditional healer should show his/her interest and be willing to become a traditional healer. According to them it is not something you can just decide on passing the knowledge to your children. One old man (76 years of age) in Bagamoyo district said that out of his 12 children only one has showed interest and was able to follow the learning process and is now practicing.

Most of traditional healers along the coast are old people of both sexes. Furthermore, the study found two categories of these traditional healers i.e. herbalists and specialists in circumcision (*Mangariba*). There are no clear boundaries or demarcation of activities between the two. It is possible to come across any from the two groups performing duties that are meant for the second group.

Knowledge dissemination

It was noted that all traditional healers disseminate their knowledge to their relatives and other community members through working together, travelling with them to heal the sick ones and when going to collect traditional medicines in the forests/bushes.

Knowledge preservation

Like craftsmen/women, the study established no evidence of knowledge preservation in traditional medicines among the coastal communities. All traditional healers interviewed do not document their knowledge on either names of trees used as medicines, ratios of mixing the medicines or ways of applying those medicines. They keep it in their heart because of the ethics of the work and fear of their expertise being stolen/ duplicated. About 67% of the respondents indicated that that there is a clear integration between indigenous knowledge and modern knowledge among traditional healers. For instance there is clear relationship between the current traditional healers and doctors working in western oriented hospitals.

Conclusion and Recommendations

This study has revealed that coastal communities have accumulated substantial knowledge on utilization and management of natural resources. This knowledge is crucial for their livelihoods. The communities were more aware and concerned about the natural resources they utilized on a day to day basis. Most coastal communities passed on knowledge through working together with their parents, brothers, sisters and other relatives. For instance knowledge among fishermen was accumulated and passed on practically through fishing, repairing fishing nets, constructing and driving fishing vessels/equipment. The same applies with craftsmen/women, farmers, traditional healers, tourist guides and traders. Nonetheless, passing on of some of the knowledge especially those related to traditional medicine depends on the attributes of the children since in most cases the practice demands strong ethics.

There is no systematic mechanism in coastal communities that is used in passing on knowledge to younger generations. The accumulated knowledge on natural resources especially old customs is not preserved. No written document was seen on knowledge preservation across the entire study areas. Also the knowledge is concentrated among the old people and very few youths have time and interest in acquiring knowledge in natural resources. This is attributed mainly to the spread of western oriented culture, desire to live sophisticated western style life, need for activities which can generate quick money, limited markets for most traditional products and possibly the effects of globalization. Most of the knowledge is disseminated through working together with parents, friends and neighbours but not in a clear systematic manner.

There is evidence of gender inequality on natural resource utilization and management. Men have dominated in fishing, tourists guiding, making of carvings, traditional healing, crab farming and harvesting and selling of most coconut palm products. Women are more engaged in farming, although they are not considered as owners of the land on which they farm and on knowledge which is more domestic in nature like using palm leaves (raphia and phoenix) in making different kinds of mats, baskets, brooms and related items. Both men and women have difficulties in passing on the knowledge to the youth for posterity.

Recommendations

1. There is evidence that there is a wealth of knowledge on natural resources among the communities living along the coastline. This knowledge is slowly disappearing as the old generation passes on. There is a need to document this knowledge in a form that will be accessible to most people and the future generations. A study should be conducted to document various practices and the knowledge on natural resource management and utilization among the coastal communities.
2. There exist no written mechanisms of acquiring and disseminating the natural resource management knowledge. Institutions or formal mechanisms should be established that can be used to disseminate this knowledge.
3. There is a need to conduct research to identify strategies of empowering women on knowledge on natural resources their utilization and management along the coastal areas of East Africa.
4. There is clear evidence that coastal natural resource knowledge base has a significant contribution to poverty alleviation among community members but there is little or scanty information on the value. There is a need to establish the economic value contribution of this knowledge to the coastal communities. This will make nations and organizations appreciate and take steps to document, preserve and disseminate the knowledge.

Suggested approaches for accomplishing the recommendations include the following:

Intensive studies and documentation of the existing knowledge

Strengthening group approaches to livelihood: women and fishermen groups have demonstrated strong capacity to share knowledge

Incorporating knowledge in school learning systems

Cultural events that promote traditional knowledge (i.e. preserving knowledge through use

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16. Factors Affecting Nutritional Attributes of *Adansonia digitata, Parinari curatellifolia, Strychnos cocculoides* and *Ziziphus mauritiana* fruits of Malawi

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Abstract

Nutritional attributes of *Adansonia digitata, Parinari curatellifolia, Strychnos cocculoides* and *Ziziphus mauritiana* fruits were significantly affected by provenance, period of harvest, extent of ripening, processing and storage condition. *Adansonia digitata* from Chikwawa fruit pulp gave the highest ascorbic acid (347.7± 3.5 mg/100g) while Mangochi fruits were richest in vitamin A (60.92 mg/kg) and iron (22.90 mg/kg). *S. cocculoides* fruits harvested in December gave significantly higher ($p< 0.001$) nutritional levels than October harvest. The levels of reducing sugars and total soluble solids (TSS) increased steadily with ripening in Z. *mauritiana* and *Strychnos* fruit pulp. The level of ascorbic acid decreased from 311.08 to 63.7 mg/100g in *Strychnos* pulp after full ripening. TSS levels were unaffected during the entire period of refrigeration. Gradual increase in TSS was observed in clay pot storage while open air afforded a steady increase. Processing *Strychnos cocculoides* into jam reduced the level of ascorbic acid by 90 %.

Key words: Harvest period, Nutritional attributes, provenance, ripening, TSS, storage

Introduction

Forests and homestead farms are important sources of non-timber products including indigenous fruits, which are consumed by communities and also sold to generate income. These are essential for food security, health, social and economic welfare of rural communities (Akinnifesi *et al.,* 2000a; FAO, 1998; Maghembe *et al.,* 1998). Fruit and other products from indigenous trees are particularly important during the hunger periods of the year and also increase rural household income through sales of fresh fruits and processed products (Akinnifesi *et al.,* 2000a; Dietz, 1999; Maghembe *et al.,* 1998). Some of the products from indigenous fruits include jam, juice, porridge and spirit.

There is sufficient evidence to show that indigenous fruits can contribute greatly to the welfare of the rural people. Nutritional studies have shown that many of the fruits are rich in sugars, pectin, essential vitamins, minerals, vegetable oils, proteins, crude fiber and total carbohydrates necessary for human nutrition (Saka and Msonthi, 1994; Kwesiga *et al.,* 2000). Improved nutrition increases immunity and reduces the effect of HIV/AIDS (Rajabiun, 2001). The rural areas are at a greater risk of HIV/AIDS, which affect food production and economic activities of people. Indigenous fruits therefore constitute an important food sources for combating malnutrition due to major deficiencies of vitamins A and C and essential amino acids as well as minerals such as iron and zinc (Thiong'o *et al.,* 2000).

Maghembe *et al.* (1992) reported that up to 97% of the households who had insufficient food stocks during the 1997/98 seasons in Malawi used indigenous fruits to minimise the situation. People living in drier parts of Zimbabwe practice more indigenous fruit processing as a way of directly or indirectly improving food security at household level (Kadzere *et al.,* 2004). In Zimbabwe some farmers in the Mukumbura area meet educational costs from money generated through sale of fruits and *Ziziphus mauritiana* gin, "Kachasu" (Kadzere *et al.,* 2004). Likewise in Mwanza district in Southern Malawi, households obtain part of their annual income through the sales of the local gin, "Kachasu", brewed from *Uapaca kirkiana* (Maghembe *et al.,* 1998). Wild foods, e.g. fruits are especially important income source for poor people since entry barriers for collection and use are low. A variety of edible wild fruits are popular natural resources in Southern Africa (Maghembe *et al.,* 1998).

The composition of these edible parts of plants is affected by several factors such as tree age, soil type, phenotype and agronomic practices and these aspects require further research (Ladipo *et al.,* 1996). Saka *et al.* (2002) reported that total and reducing sugars are significantly different within and among groups of indigenous fruits and are also influenced by storage conditions. Indigenous fruits are mainly consumed as fresh or as limited fruit products (Kadzere *et al.,* 2004). These are either sold locally, or sometimes transported to urban areas. Fresh fruits take time to reach towns due to poor road infrastructure in the region especially Malawi and may lose quality with ripening.

Climatic conditions, particularly temperature and light intensity have strong effects on the nutritional quality of fruits (Mozafar, 1994). For instance, Sidibe *et al.* (1996) assessed the tree-to-tree variation in vitamin C content of *Adansonia digitata* fruits from the Black, Red and Grey bark types in 2-3 trees from 4-5 villages in three areas of Mali receiving different rainfall amount. The vitamin C content varied 3-fold between trees, but there were no consistent differences in vitamin C content between zones or tree types. Maturity at harvest influences quality and extent of physical injuries. Therefore delays between harvest and consumption may result in losses of flavour and nutritional quality. Aydin and co-researchers studied changes in the chemical composition, polyphenol oxidase (PPO) and peroxidase (POD) activities during development and ripening of medlar fruit (*Mespilus germanica L*) and established that during the early stages of fruit development, PPO activity and the level of ascorbic acid gradually decreased, whereas in the post ripening stage PPO activity increased (Aydin *et al.,* 2001).

Fresh fruits are highly perishable and incur direct or indirect nutrient and quality losses between the field and the consumer. For instance, long distance transportation of pepino reduced their quality in terms of sensory and nutritional attributes and shelf life is often shorter when arriving at the wholesale or retail market and does not correspond with consumer requests (Huykens *et al.,* 2000). Indigenous fruit producers/collectors encounter post-harvest problems such as rapid deterioration of fresh ripe fruits, which particularly is the case with *U. kirkiana* and *Z. mauritiana* (Kadzere *et al.,* 2004). Fruits of *Z. mauritiana* are also susceptible to the compression and pest damage (Rao and Kwesiga, 2004). The major causes of losses include mechanical damage (cracking, compression, and bruising) during harvesting and transportation, insects and pest damage, and over ripening. Mechanical damage accounts for the highest loss in *U. kirkiana* whilst insect and pests and rots in *Z. mauritiana* and *P. curatellifolia* (Kadzere *et al.,* 2004). To overcome these problems producers/collectors, marketers, consumers and vendors should be trained in proper harvesting and post-harvest handling techniques (Rao and Kwesiga, 2004).

Leakey (1999) reported that the ascorbic acid content of *Dacryodes edulis,* a nutritious indigenous fruit of Cameroon is lost by some forms of cooking. This is because ascorbic acid is water soluble and unstable to heat and may therefore decompose to other substances.

The aim of this study was to investigate the effect of provenance, harvesting period, ripening, storage condition and tree age and processing on nutritional attributes of *Adansonia digitata*, *Parinari curatellifolia, Strychnos cocculoides,* and *Ziziphus mauritiana*.

Materials and Methods

Fresh fruits collected in October and December in 2005 from the different provenances; *Adansonia digitata* was collected from Chikwawa, Dedza, Mangochi, Mwanza and Salima districts while P*arinari curatellifolia* was collected from Katope and Kaning'ina (Mzimba district), Sanga (Nkhata Bay district) and Nkhamenya (Kasungu district); *Strychnos cocculoides* was collected from Nkhamenya and Sanga while *Z. mauritiana* was from Dedza, Chikwawa and Mangochi districts. Fruits from different provenances were kept separately. Ripe and unripe fruits of *S. cocculoides* and *Z. mauritiana* were sorted before further treatment. Fresh fruits were thoroughly cleaned to remove dirt and plant debris.

Chemical analysis

Extraction and determination of ascorbic acid. Fruit pulp (2.0 g), in duplicate was homogenised in extracting solvent system (0.38 M HPO_3 + 1.38 M HOAc, 100 mL), for two minutes at medium speed, and allowed to stand for 30 minutes in a refrigerator for the supernatant to settle before determination. Ascorbic acid was determined by redox titration using standardised 2, 6 dichlorophenol-indophenol dye (DCIP) which is blue in alkali, pink in acidic medium and colourless in ascorbic acid. The concentration of ascorbic acid was expressed as (mg/100g). Fruit supernatant (10.00 mL) in triplicate were transferred into a well-rinsed and dried conical flask, and titrated against DCIP until end point (pink coloration) (scheme 16.1).

Extraction and determination of retinoic acid was under taken using UV Methods for Micronutrient Determination. Accurately weighed fruit samples in duplicate were transferred into dried extraction conical centrifuge tubes (50.0 mL) and mixed with magnesium carbonate (1.0 g). Dichloromethane (8.0 mL), methanol (2.0 mL), and distilled water (12.0 mL) were added in turn with a 30-second vortexing separation after each addition. The resultant mixtures were centrifuged by a CENTRA CL2 Centrifuge (Thermo Electron Corporation, Milford, USA) for 4 minutes at 1000 revolutions per minute. Three layers were formed: organic (bottom), residues suspended in organic layer (middle) and aqueous on top. The two top layers were decanted carefully, and organic layer (5.0 mL) was diluted to 50.0 mL mark in a brown volumetric flask with dichloromethane. The solutions were kept in the dark (room temperature) for 15 minutes to equilibrate before analysis. The absorbance values for standard solutions were obtained at 325 nm using a JENWAY 6405 UV/Vis spectrophotometer (ESSEX, London, UK) and plotted against actual concentration (AOAC, 1990). The absorbance of the samples was measured and the concentration of vitamin A in the fruit pulp digest determined from the standard calibration plot. The level of retinoic acid was expressed as (mg/kg).

All other Nutritional attributes (reducing sugars, total soluble solids, acidity, pH, moisture content and minerals) were analysed using standard methods described in AOAC (AOAC, 1990).

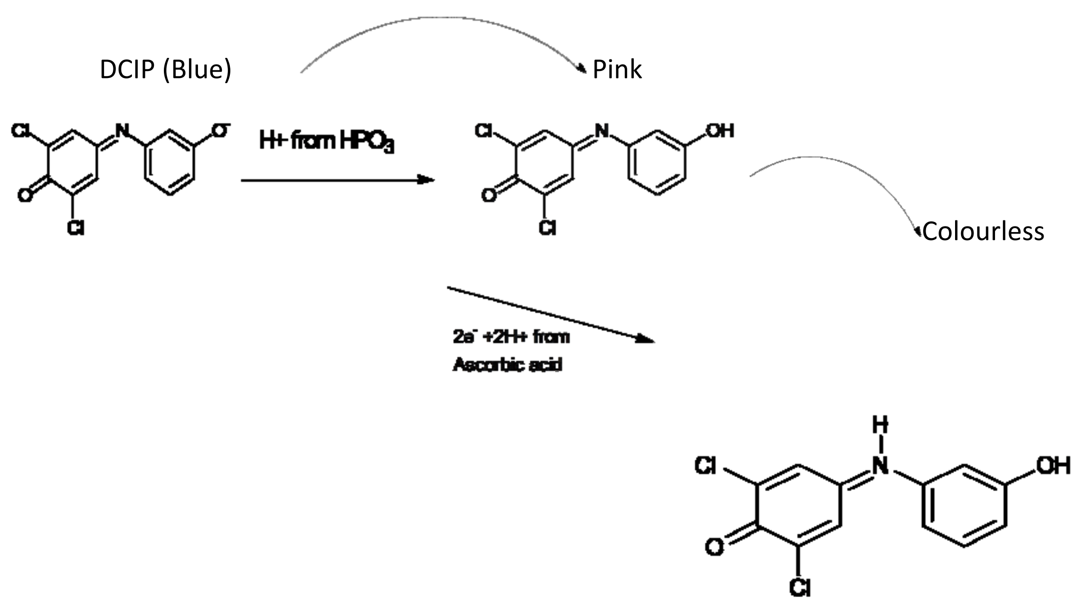
Data analysis

The data was analysed using analysis of variance performed using the Genstat Discovery edition (Genstat, 1999) to test the effect of provenance, ripening, harvesting period, tree age, processing and storage condition on the levels of nutritional attributes. Statistical significance was tested at $p < 0.05$ and Minas were separated using Least Significance difference (LSD).

Results and Discussions

Effect of provenance on some nutritional attributes of fruits

The results of the nutritional attributes analysis of fruit samples from different provenances are shown in Table 16.1.



Scheme 16.1: Reduction of DCIP to $DCIPH_2$ during redox titration

Table 16.1. Effect of provenance on physico-chemical properties of three fruit species

Provenance	***Adansonia digitata* (Analyte)**												
	Vit. A (mg/kg)	Vit.C (mg/100g)	R.sugar (%)	Acidity (%)	pH	DM (%)	TSS (%)	Ca (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	K (mg/kg)	Mg (mg/k)	Na/ mg/kg
Chikwawa	35.83	347.70	11.27	2.58	3.19	32.03	21.80	1956	2.48	19.60	979	20.30	166.90
Dedza	31.08	259.70	8.75	2.20	3.25	32.47	32.50	2786	5.02	15.30	766	10.40	172.30
Mangochi	60.92	239.30	10.18	2.86	3.14	32.53	32.03	1958	1.68	22.90	1172	26.20	252.90
Mwanza	54.71	317.00	10.22	2.40	3.16	32.50	30.63	2269	4.14	17.60	530	21.20	282.30
Salima	29.86	233.10	9.01	2.68	3.43	33.80	31.87	1978	3.58	16.40	1142	33.60	248.20
LSD (0.05)	1.25	12.30	0.19	0.15	0.01	1.27	5.29	1.46	7.46	4.82	10.61	58.84	1.74
CV (%)	1.60	2.30	1.00	3.10	0.20	1.00	5.10	12.80	22.90	21.60	25.00	25.20	13.90
Sign. level	0.001	0.001	0.001	0.001	0.001	0.092	0.001	0.027	0.005	0.241	0.007	0.011	0.006

	***Parinari curatellifolia* (Analyte)**							***Ziziphus mauritiana* (Analyte)**				
Provenance	Vit. A (mg/kg)	Vit.C (mg/100g)	R.sugar (%)	Acidity (%)	pH	DM (%)	TSS (%)	**Provenance**	Vitamin C (mg/100g)	R. sugar (%)	Acidity (%)	TSS (%)
Katope	32.39	25.17	25.17	0.08	3.54	25.64	25.10					
Kaning'ina	9.80	23.51	10.20	0.05	3.48	28.17	23.20	Chikwawa	37.19	15.94	0.19	19.17
Nkhata bay	12.31	134.64	8.43	0.10	4.07	24.10	26.10	Dedza	73.38	15.48	0.36	15.08
Nkhamenya	11.64	41.38	3.92	0.07	3.65	28.29	23.80	Mangochi	88.05	15.11	0.48	13.95
LSD (0.05)	1.16	5.68	0.16	0.02	0.03	0.98	4.0		3.80	0.75	0.04	2.10
CV (%)	5.80	8.20	2.00	24.40	0.70	3.30	13.00		21.20	3.80	8.50	10.20
Sign. level	0.001	0.001	0.001	0.001	0.001	0.001	0.38		0.001	0.092	0.001	0.001

Parinari curatellifolia fruits from Katope (Mzimba) had significantly higher ($p<0.001$) levels of vitamin A and reducing sugars compared to all. The least vitamin A levels ($p<0.001$) were observed in the Kaning'ina fruit provenance. No significant difference existed in vitamin A levels for the sample fruits from Nkhata Bay and Nkhamenya ($p >0.05$). Fruits from Nkhata Bay provenance exhibited significantly highest levels of ascorbic acid and total soluble solids ($p<0.001$) than other provenances. This is probably due to differences in soil types. Ascorbic acid content in Nkhata Bay fruits was five-fold more than Katope and Kaning'ina fruit provenances. All fruits were generally acidic. The total soluble solids varied from 23.17±2.27 to 26.12±4.70% for all provenances. No significant variation existed in TSS levels ($p>0.05$) amongst fruits from Katope, Kaning'ina and Nkhamenya. The reducing sugar levels were significantly different amongst all provenances ($p<0.001$). The Katope provenance gave significantly highest levels of reducing sugars (25.17±4.37%) while Nkhamenya registered the least (3.92±0.05%). The variations in nutrient content could be genotypic, environmental or geographical attributes and this agrees with findings by Mpofu *et al.* (2006).

On the other hand *Zizyphus mauritiana* from Mangochi provenance gave significantly higher vitamin C (88.05 mg/100g) and acidity (0.48%) than Chikwawa and Dedza provenances. In contrast, the significantly higher total soluble solids and reducing sugar levels ($p<0.001$) were obtained in *Z. mauritiana* fruits from Chikwawa provenance. For *Adansonia digitata* fruits from Chikwawa had significantly higher ($p<0.001$) ascorbic acid and reducing sugar levels than the rest (Table 16.1). Values as high as 347.7 mg/100 g and 11.27 % respectively were obtained. *A. digitata* from Salima had significantly least levels of vitamin A and C ($p<0.001$). Other studies have also established that differences in nutritional quality of same fruit genotype may be due to variation in soil types, altitude, soil pH and climate (Goldman *et al.,* 1999 and Gross, 1991). Gross (1991) reported that light intensity is proportional to sugar synthesis by the fruit (glucose being the precursor of vitamin C). Generally, fruits from all sites were acidic. However, minor differences within provenances were observed (Table 16.1). Mangochi fruits were the most acidic ($p<0.05$). Osman attributed this as due to the presence of high amino acids content (glutamic and aspartic) as well as ascorbic acid in *A. digitata* fruit pulp (Osman, 2004). The total soluble solids ranged from 21.80 to 32.50% and the Dedza provenance showed significantly higher levels while Chikwawa the least ($p<0.001$). The fruit pulp of *A. digitata* from Mangochi and Mwanza had significantly highest levels of vitamin A ($p<0.001$); 60.92 and 54.71 mg/kg respectively. Chikwawa and Salima fruits afforded only 35.83 and 29.86 mg/kg vitamin A respectively. Mwanza and Dedza provenances showed significantly higher ($p<0.05$) calcium content than fruits from the other three sites. Mangochi and Salima had significantly highest ($p<0.05$) potassium level. This is possibly due to differences and similarities in soil types and rainfall patterns from other sites. Mangochi and Salima are along Lake Malawi shores hence may share similar rainfall patterns and soil properties.

Effect of harvesting period on Nutritional attributes of Strychnos cocculoides

The results of the analysis of important nutritional attributes of *Strychnos cocculoides* (Table 16.2) are shown in Figure 16.1. The results showed that both period of harvest and fruit condition have strong influence on nutritional level of plant material. Significant differences existed in nutritional levels of *Strychnos* at the two harvesting times ($p<0.001$). The levels of vitamin C, reducing sugars, calcium, iron, magnesium and sodium levels were significantly higher ($p<0.001$) in fruits harvested in December than October (Figure 16.1).

In contrast, acidity levels were significantly higher ($p<0.001$) in October than December harvest. This is possibly due to large amount of organic acids like citric acid which are later (December) converted to other organic compounds. High levels of reducing sugars in December fruits entails high glucose level, the raw material for vitamin C. In recent studies, Kadzere and co-researchers reported that delaying harvesting of *Uapaca kirkiana* fruits help to improve quality attributes such as skin colour at harvest and during storage, to reduce weight loss and obtain higher soluble solids concentration (SSC) (Kadzere *et al.,* 2006 and 2007). For instance, late harvested fruits had SSC varying from 11.8% in greenish-yellow fruit to 14.4% in browner fruits versus 6.7% to 13.8% for the early harvested fruits. Reducing sugars and total soluble solids levels were significantly higher ($p<0.001$) in ripe fruits than unripe fruits for both harvesting seasons. The two variables (reducing sugars and total soluble solids) were significantly higher ($p<0.001$) in ripe fruits than unripe counterparts. Iron, magnesium, sodium and zinc levels were significantly decreased ($p<0.001$) in ripe fruits. Thus harvesting of *S. cocculoides* in December assures quality fruits in terms vitamins and sugar levels.

Table 16.2. Nutritional levels of *S. cocculoides* harvested in October and December

Analyt/ Nutrient	Fruit condition				**LSD (0.05)**		**Sign. Level**	
	Mature (unripe)		Mature (ripe)					
	Oct	Dec	Oct	Dec	Oct	Dec	Oct	Dec
Vit C (mg/100g)	20.20	25.95	15.53	20.02	0.32	1.22	0.001	0.001
R. Sugars (%)	3.42	9.41	7.69	10.90	7.68	0.04	0.001	0.001
Acidity (%)	0.94	0.23		0.35	0.09	0.04	0.001	0.001
Ca (mg/kg)		22.76	1.56	25.60	0.75	2.59	0.001	0.001
Cu (mg/kg)	18.14	0.76	7.95	0.77	0.07	0.14	0.001	0.85
Fe (mg/kg)	0.95	15.71	0.60	12.39	4.60	1.58	0.004	0.001
K (mg/kg)	15.70	38.10	8.80	41.44	0.85	2.88	0.001	0.001
Mg (mg/kg)	32.09	7.70	26.99	5.20	0.12	6.52	0.001	0.42
Na (mg/kg)	5.70	109.40	4.24	81.90	0.33	17.41	0.001	0.004
Zn (mg/kg)	48.51	3.72	44.00	3.06	0.25	0.70	0.001	0.065
	4.03		2.77					

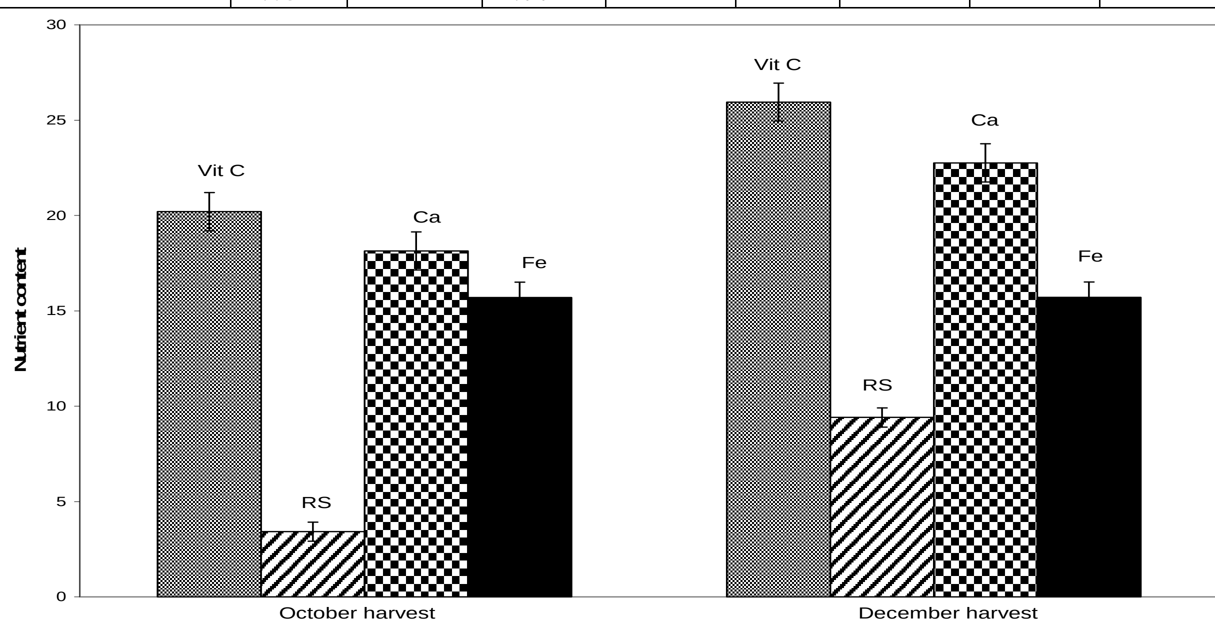


Figure 16.1 : Nutrient levels of *S. cocculoides* fruit pulp for two harvesting times

Effect of ripening on some Nutritional attributes

Fruit developmental stage affects fruit quality and the resultant products. Although fruits are much appreciated when harvested after full ripening, pre-ripe harvesting for some fruits, including mangoes, can otherwise be recommended (Kansci *et al.,* 2003). The importance of state of ripening at harvest is primordial as notable changes occur in the fruit during ripening which improved its physicochemical and sensory characteristics. For Strychnos *cocculoides* the results for changes of nutrient levels with storage time (ambient air storage condition) in both mature and ripe fruit pulps of *S. cocculoides* are presented in Table 16.3.

The results showed that generally reducing sugars and total soluble solids were increasing until peak ripening when these variables started decreasing. Such a decrease could be due to dilution effect evident from a decrease in dry matter content with ripening (Table 16.3). The levels of vitamin C were decreasing with ripening. Cell wall components undergo changes after harvest as a consequence of the action of various enzymes and all these account for the increase in TSS and reducing sugars with ripening (Aydin *et al.,* 2001). McWilliams reported that the pectic substances in cell walls and middle lamella undergo degradation as a result of the increasing levels of two types of enzymes: pectinesterases and polygalacturonases (McWilliams, 1993). The action of pectinesterases is valued in making apple and grape juices because of the increased solubility of the degraded pectic substances, notably pectic acid, promotes a less cloudy beverage and increases the visual appeal of the juices. Other enzymes include hemicellulase and cellulase. As a consequence of the reactions catalysed by these enzymes, some sugars are released from the complex polysaccharides constituting the cell walls. The result is that ripening fruits increase in sweetness despite the fact that they may have little or no starch to serve as a potential source of sugar.

Table 16.3. A change of Nutritional attributes with storage time for *S. cocculoides* fruit pulp

Fruit condition	Time (hours)	Physicochemical properties				
		Vit.C (mg/100g)	Red. sugar (%)	TSS (%)	Acidity (%)	Dry matter (%)
Mature (unripe)	0.00	306.25	2.42	16.64	0.94	25.11
	72.00	276.11	3.46	18.92	1.43	25.28
	144.00	285.07	3.05	18.14	1.04	26.52
Ripe	0.00	53.91	7.69	16.11	1.56	22.63
	72.00	93.66	5.85	17.96	1.87	23.49
	144.00	35.24	4.10	17.43	1.46	23.55
LSD (0.05)		**24.51**	**0.62**	**1.82**	**0.25**	**2.71**

For Z*izyphus mauritiana* results showed that in general total soluble sugars, reducing sugars and vitamin C levels increased with ripening. In some fruits, ascorbic acid level increases greatly while in others, it remains unchanged or decrease. The increase or decrease of the ascorbic acid and dehydroascorbic acid levels from precursors also affect both enzymatic and non-enzymatic factors. The balance between these factors assures the final content and underlies the variation of ascorbic acid level during ripening. Chapman and Horvat (1993) found that the total ascorbic acid level in *Mespilus germanica* fruits increased in the pre-ripening stage followed by a decrease in the post- ripening stages and the level of glucose gradually increased during fruit development and ripening. For some fruits including *P. curatellifoli,* and *S. cocculoides* many reactions still occur during fruit ripening, such as colour transformation, sugar synthesis and cell wall degradation. All these phenomena may cause tissue stresses, which would require antioxidant action especially by ascorbate, preventing cell damage. Due to these stresses ascorbic acid levels would invariably decrease during fruit ripening.

Effect of storage condition on total soluble solids of Z. mauritiana fruit pulp

Figures 16.2a, 16.2b and 16.2c revealed that storage conditions significantly affected the change in total soluble solids (TSS) with time in *Z. mauritiana* fruits ($p<0.001$). Fruits kept in open air showed significantly increased TSS levels ($p<0.001$). For instance, % TSS for initially unripe (UR) fruits increased from 11.71% to 15.5% over a 48 hour period of storage. Similarly TSS levels for slightly (SR) ripe (R) and very ripe fruits (VR) increased steadily under ambient air storage condition (Figure 16.2a). Higher temperatures under open air provided favourable conditions to enzymes for metabolic processes like cell wall degradation leading to the release of soluble sugars hence increase in TSS levels.

Negligible and gradual changes in TSS levels were observed for fruits kept in the refrigerator and clay pots respectively. The levels under refrigerator storage condition were nearly constant. For instance, SR fruits gave 17.68% of TSS at time zero while 17.0% was determined after 48 hours of refrigeration (Figure 16.2b). For clay pot storage the % TSS for the unripe fruits increased for the first 24 hour period from 13.9% to 16.2% but dropped to 13.8% after the next 24 hours (Figure 16.2c).

The lower temperatures in the clay pots accounted for significantly lower change with time ($p<0.05$) in TSS levels than fruits under open air. The physiological activities were inhibited by very low refrigerator temperatures while normal metabolic processes were being carried on under open air storage hence the observed effects. Similar results for the effect of storage temperature on the post-harvest quality were reported in *Solanum muricatum* (Pepino) (Widayat *et al.,* 2003).

Effect of tree age and jam processing on nutritional attributes of Strychnos fruit pulp from young, middle and old aged fruit trees

Jam prepared from different fruit ripening stages and tree age groups of *S. cocculoides* had their physicochemical properties analysed then compared with fresh edible pulp. Vitamin C and reducing sugar levels of fresh fruits (FY, FM, FO) and their jams (JY, JM, JO) from young, middle and old fruit trees including reducing sugars are summarised in Figure 16.3.

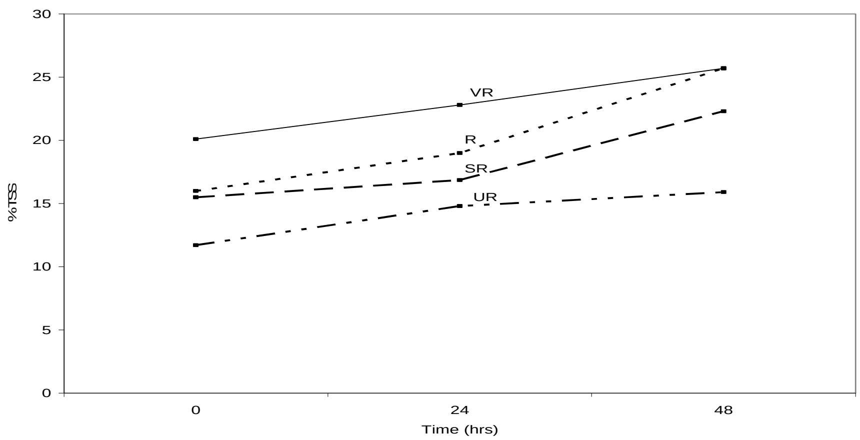


Figure 16.2a: Effect of ambient air storage conditions on % TSS of *Z. mauritiana*

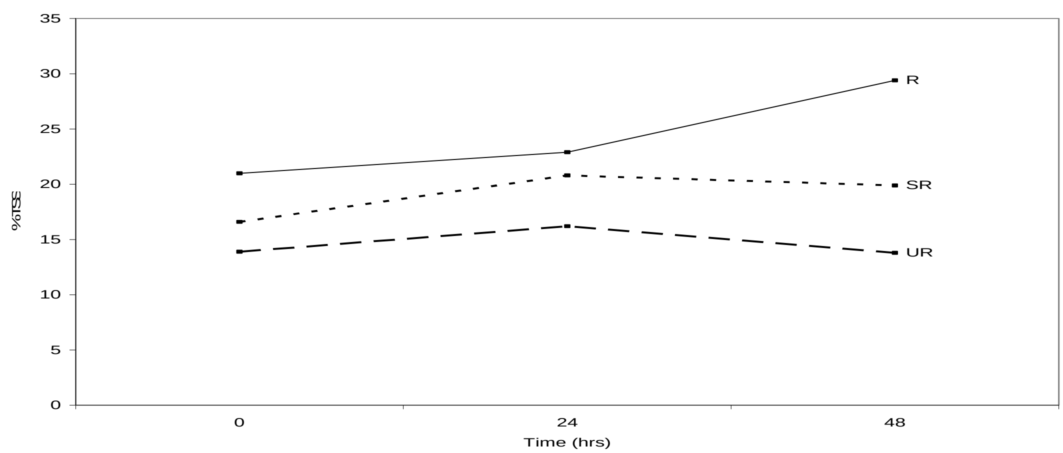


Figure 16.2b: Effect of refrigerator storage conditions on % TSS of *Z. mauritiana. Key: R, ripe; SR, slightly ripe; UR, unripe*

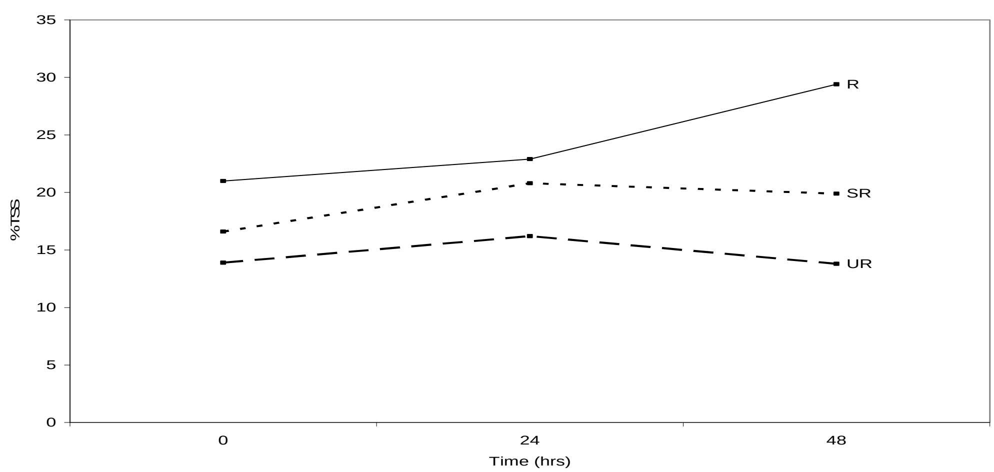


Figure 16.2c: Effect of clay pot storage conditions on % TSS of *Z. mauritiana. Key: R, ripe; SR, slightly ripe; UR, unripe*

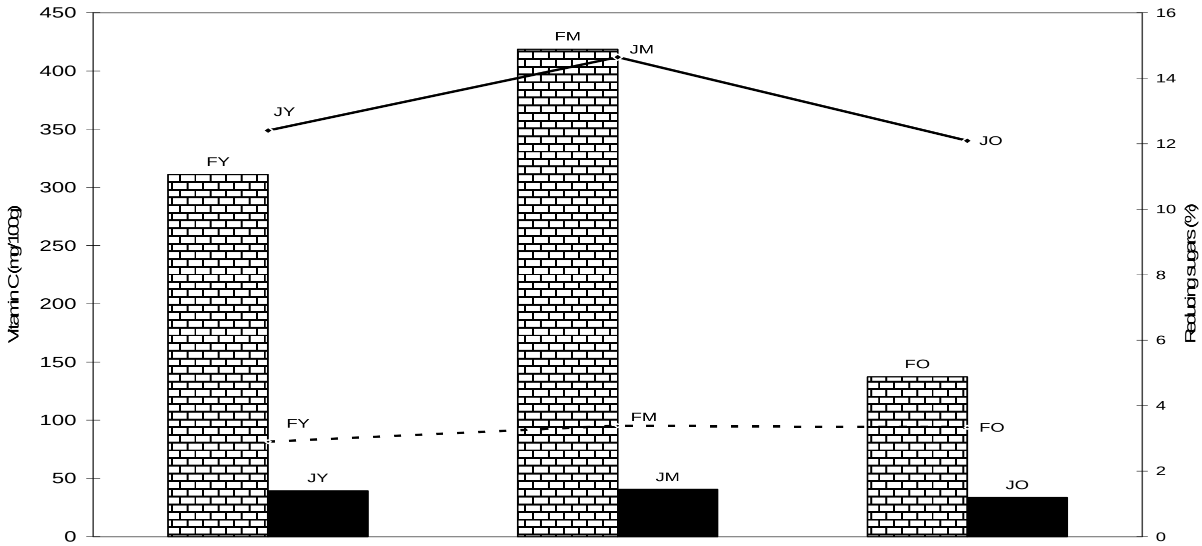


Figure 16.3: Effect of jam processing on nutritional levels of *S. cocculoides*. ***Key:*** *YF, Fresh fruits from young aged trees and their jam (YJ); MF, Fresh fruits from middle aged trees and their jam (JM); OF, Fresh fruits from old aged trees and their jam (OJ)*

Processing affected the composition of the final produced jam from *Strychnos* fruits from three tree age groups. Ascorbic acid decreased significantly during the production of jam while reducing sugars increased ($p<0.001$). For example, unprocessed *Strychnos* fruit pulp from middle aged fruit trees (MF) showed significantly higher ascorbic acid level (418.56 mg/100 g) but only 40. 66 mg/100 g was retained after jam processing (Figure 16.3). This represented more than 90% loss in the final product. On the contrary, reducing sugar was 14.39% in the jam representing more than 320 % increase. Significant losses of vitamin C could be due to pressing and heating during jam preparation. Vitamin C might have passed into the liquid phase during processing. Further to that, vitamin C, which is unstable to heat and oxygen was easily oxidised to nonantioxidant effective substances. Increase in reducing sugar content was due to extra sucrose added during jam production which undergoes hydrolysis to fructose and glucose during heating.

Conclusions

Provenance affected the nutritional quantity of fruits with *Adansonia digitata* from Chikwawa exhibiting higher vitamin C levels on fresh weight basis than those from Mangochi, Salima, Dedza, and Mwanza. *A. digitata* fruits from Mangochi were very rich in vitamin A. On the other hand *Parinari curatellifolia* from Nkhata Bay had highest level of vitamin C while for *Zizyphus mauritiana* fruits from Chikwawa were richer in vitamin C than those from Mangochi and Dedza. In general provenances richer in vitamin C had low levels of vitamin A. It is therefore, necessary to have information about superior provenances for a particular nutrient being sought. The period of harvest significantly affected nutritional quantity of *S. cocculoides* fruit pulp. Important nutrients such as vitamin C and iron were significantly higher for December than October harvest. Thus fruits *of Strychnos cocculoides* harvested late in the season ensure consumption of quality fruits and derived products. Fruit tree age significantly affect nutritional quantity of *Strychnos* pulp. For instance, fruits from middle aged trees had highest levels of vitamin C while those from old aged trees gave highest acidity.

Ripening affected nutritional levels of fruit pulps for example *S. cocculoides*, vitamin C content decreased with ripening while for Z. *mauritiana* it was increasing. In both fruit species, reducing sugars and total soluble solids increased with ripening. Over-ripened *Strychnos cocculoides* and *Ziziphus mauritiana* pulp had lower vitamin C and sugar levels due to dilution effect and transformation to other organic compounds as a result of oxidation and stress.

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17. Characterisation of *Uapaca kirkiana* Müell. Årg Provenances Using Morphological Traits

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Abstract

Domestication of *Uapaca kirkiana* Müell. Arg is a high priority for improving rural livelihoods of smallholder farmers in southern Africa. Domestication efforts require knowledge of adaptive traits and intra-specific variation. Morphological traits were used to assess genetic variation in twelve provenances of *U. kirkiana* collected from southern Africa. Assessment of tree morphological attributes showed significant differences ($p < 0.05$) between provenances. Provenances from Zimbabwe and Zambia grew much faster in Malawi than those from Malawi (except Phalombe) and Tanzania. The differentiation for some morphological traits could be attributed to local adaptation and human selection of the *U. kirkiana* trees at the site of origin.There was no geographical pattern of variation in growth and morphological traits among the seed sources but Mapanzure provenance from Zimbabwe was the least diverse provenance but superior in height growth and earliest in fruiting. The pattern of morphological diversity and adaptive traits in *U. kirkiana* indicates existence of genetic drift and high gene flow between provenances suggesting that regional, country collections and conservation strategies should consider differences by focussing on the main range of the species.

Key words: Conservation, Domestication, Genetic diversity, Provenance, *Uapaca kirkiana*, UPGMA

Introduction

Uapaca kirkiana Müell. Årg (family Euphorbiaceae) is a tree indigenous to the miombo woodlands of eastern, central and southern Africa (Ngulube *et al.,* 1995). The tree can grow in the range of 11 to 13 metres with a juvenile phase of 9 to 10 years for planting materials derived from sexual propagation, while vegetatively propagated materials can take 2 to 4 years to fruit (Mhango, 2000; Akinnifesi *et al.*, 2006). The seed is dispersed by humans and animals such as birds, bats, monkeys and rodents (Ngulube *et al.,* 1995). Several studies have reported the utilization of *U. kirkiana* fresh and processed fruits as important source of nutrients and income to local communities (Saka *et al.*, 2008; Ham *et al.*, 2008). A regional-wide survey undertaken to determine needs and preference of farmers and various users in southern Africa had identified *U. kirkiana* as a priority indigenous fruit tree for utilization, conservation and domestication (Maghembe *et al.,* 1998; Akinnifesi *et al.,* 2004a). Although *U. kirkiana* is not commercially cultivated, but efforts are in progress to domesticate and commercialise it in southern Africa (Akinnifesi *et al.*, 2006), and it forms part of a global initiative to promote indigenous fruit trees in agroforestry for community livelihood benefits (Leakey *et al.*, 2005). As part of a larger domestication program by the World Agroforestry Centre (ICRAF) and its partners in southern Africa, had an extensive range-wide germplasm collection done in five countries namely: Malawi, Mozambique, Tanzania, Zambia and Zimbabwe—as the first step in a domestication strategy (Akinnifesi *et al.*, 2004b; 2008). These collections provided materials for assessments, conservation and future utilization in live gene banks, as regional multi-locational provenance trials were established from the collections in 1996 in Malawi, Zambia and Zimbabwe (Akinnifesi *et al.*, 2004b). Conservation of genetic diversity is a fundamental goal of conservation biology and knowledge of the extent and structure of genetic variation in provenances of *U. kirkiana* is essential not only for understanding processes of evolution, but also for development of appropriate and efficient strategies for collection, conservation and domestication of superior populations that can with stand climate change and weather fluctuation. Studies on genetic diversity of provenances from southern Africa will be crucial for determining strategies to ensure that greatest amount of genetic variation is captured for adaptation to drought and other climate change factors.

Understanding the morphological and phenological variations among trees, fruits, seeds and seedlings (Mwamba, 1995; Ngulube *et al.,* 1997; Mwase *et al.,* 2006a) from populations derived from different geographical areas is central to the study of genetic diversity. Although diverse geographical origin *per se* cannot be considered a genetic parameter, traits like growth rate have the advantage of direct relevance. The present study is part of a wider project, which seeks to explore opportunities for the selection, domestication and cultivation of *U. kirkiana* in southern Africa (Akinnifesi *et al.,* 2008). The aim of this study was to assess the level of morphological and adaptive traits variation within and among *U. kirkiana* provenances of southern African based on morphological tree attributes and recommend appropriate germplasm collection and conservation strategies.

Materials and Methods

Seed sources

Range-wide collections of *U. kirkiana* provenances were made from five countries of southern Africa, namely: Malawi, Mozambique, Tanzania, Zambia and Zimbabwe during November 1995 and January 1996 (Akinnifesi *et al.,* 2004). Seeds were randomly collected from 15 - 20 superior trees of twenty four provenances and exchanged among the five countries making sixteen provenances and twelve of which are part of this study (Table 17.1). The four countries represent part of the geographical range of natural distribution of *U. kirkiana* in southern Africa region defined by geographical and political boundaries (Figure 17.1). The seedlings were established in multi-location trials with 12 to 16 provenances in each of the four countries, i.e. at Chipata in

Zambia, Iringa in Tanzania, Domboshawa in Zimbabwe and Makoka in Malawi (Akinnifesi *et al.*, 2004b; 2006). Randomized complete block design with 20 replications was the experimental design used across the countries. Each treatment consisted of a line-plot of four-trees planted at 2m spacing within row and 4m between rows. The data reported in this study is based on the data collected from the provenance established at Makoka Agricultural Research Station in Zomba, in southern Malawi (15^0 30’ S and 35^0 15’ E; altitude 1029 m above sea level). The rainfall is unimodal, with most of the rain occurring from November to April. The total annual rainfall ranges from 560 to 1600 mm, with a 30-year mean of 1024 mm. The soils at the site are classified as Ferric Lixisol (FAO/UNESCO). The soil texture is 46% sand, 46% clay and 8% silt. The clay content in the site increases with soil depth, but major chemical characteristics are relatively constant to > 1 m depth (Akinnifesi *et al.,* 2008).

Measurements of growth and morphological traits

Tree height, diameter at breast height and root collar diameter were measured every year from 1998 to 2006. Height was measured to the nearest centimetre using a telescopic measuring pole and diameter using calipers. In addition each tree was scored subjectively for morphological traits: stem straightness; branch angle; length of primary branches, crown depth and fruiting. Details of the scoring procedures are provided in Table 17.2.

Table 17.1: Source of germplasm of *U. kirkiana* established at ICRAF - Makoka, Zomba in Malawi

Code	Provenance	Country of origin	Latitude (^{0}S)	Longitude (^{0}E)	Elevation (m)	Rainfall (mm)
1	Phalombe	Malawi	16º09'	34º29'	1260	1000
2	Chimaliro	Malawi	12º15'	33º50'	1338	1200
3	Litende	Malawi	11º49'	34º10'	1120	1500
4	Chipata	Zambia	13º40'	32º40'	1050	980
5	Choma	Zambia	16º51'	27º04'	1200	800
6	Serenje	Zambia	13º03'	30º37'	1559	1200
7	Mpwapwa	Tanzania	6º05'	35º46'	1330	550
8	Mbeya Kyela	Tanzania	9º45'	33º30'	>2000	1500
9	Iringa	Tanzania	7º50'	35º46'	1540	1100
10	Nyamukwarara	Zimbabwe	18º40'	32º55'	1800	1450
11	Murehwa	Zimbabwe	17º40'	31º50'	1470	800
12	Mapanzure	Zimbabwe	20º20'	31º00'	1100	650

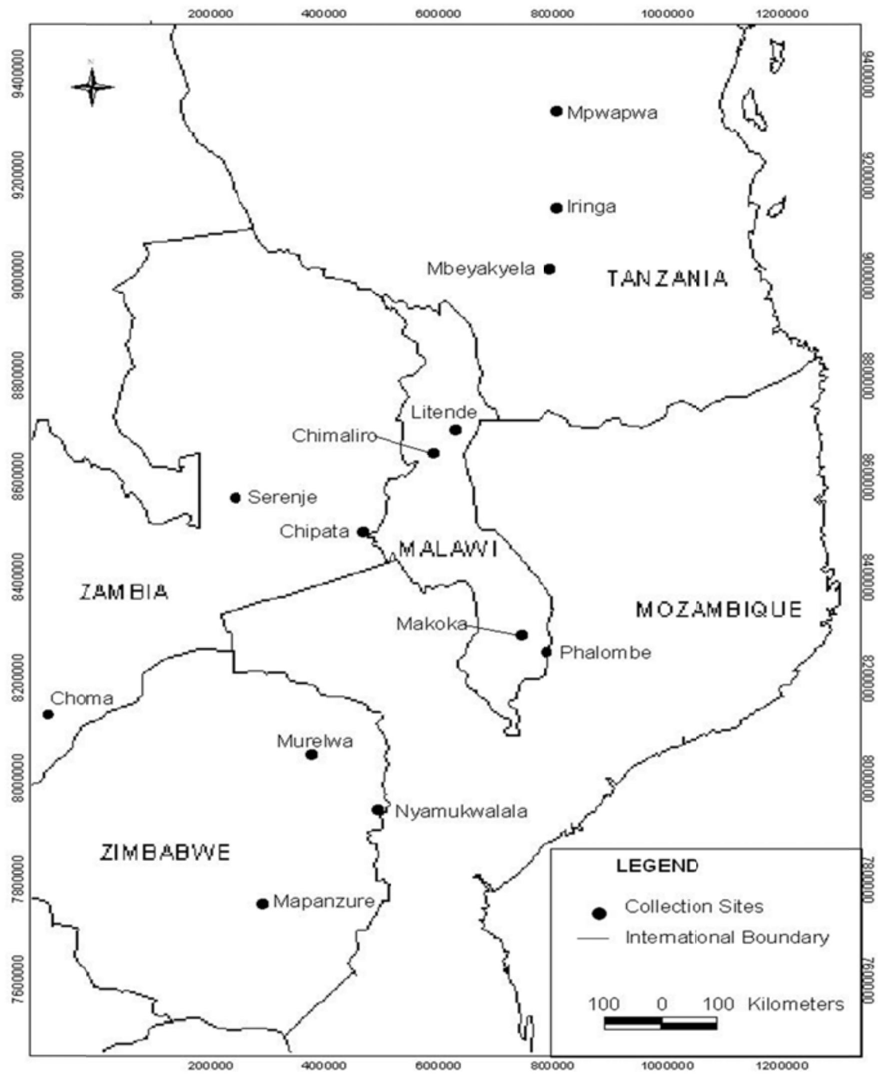

Figure 17.1: Map of southern African countries showing locations of twelve provenances as sources of germplasm planted at ICRAF-Makoka, Zomba in Malawi

Statistical analysis

Analysis of variance for growth traits was performed across provenances and separately within each country of origin using the general linear model in MINITAB 14.0. Variance across provenances was analyzed according to a linear model with the following sources of variation: provenance and replication as random terms and country as a fixed term. The standardized traits mean values of the morphological data were used to perform cluster analysis using NTSYS pc 2.1 (Rohlf, 2000) and a dendrogram was constructed using the unweighted pair group method of arithmetic average (UPGMA). Genetic distances between provenances were calculated with the squared Euclidean distance (Sneath and Sokal, 1973).

Table 17.2. Growth and morphological traits of *Uapaca kirkiana* and their description

Trait	**Unit**	**Explanation**
Quantitative traits		
Total Height	cm	measured from root collar to tip
Bole height	cm	measured from the root collar to first living branch of the tree crown
Diameter at breast height	cm	measured at 1.3 m above ground
Root collar diameter	cm	measured at 3 cm above the soil surface
Bark thickness	cm	measured using bark gauge at 3 cm above soil surface
Crown depth	cm	Measured from starting point of branches to stem tip
Branch length	cm	measured from stem to branch tip for primary branches
Branching habit		
Branch angle	1-2	1= upright, < 60^0; 2= horizontal >60^0
Branchlet length	cm	measured from stem to branch tip for two randomly selected branches per whorl
Qualitative traits		
Stem straightness	1-5	1 = not vertical > 2 bends
		2 = roughly vertical >2 bends
		3 = roughly vertical, 1-2 bends
		4 = roughly vertical and straight
		5 = completely vertical and straight
Survival	Percent	Based on 4 tree –row plot
Reproduction		
Fruiting	1-2	1 = yes ; presence of fruits
		2 = no: not fruiting

Simple matching coefficients of similarity (Sneath and Sokal, 1973) were calculated for all pair wise comparisons among provenances. Matrices of Euclidean dissimilarity coefficients based on morphological data set were tested for correlation using the Mantel test. A matrix of geographical distances among provenances was obtained (http://.www.jan.ucc.nau.edu/-cvm/latlongdist.html) and compared with the corresponding simple matching similarity coefficients to investigate possible association between geographical and genetic distance (MXCOMP in Mantel test in NTSYS). Morphological data sets were subjected to principal component analysis (PCA) (Esbensen *et al.,* 2007) in Unscrambler 9.7 to investigate further relationships among provenances.

Results

Morphological traits of provenances

The mean absolute values of the 14 growth and morphological characters used in the characterization are presented in Table 17.3. Differences within the southern Africa region were highly significant ($p < 0.001$) for diameter at breast height (dbh) and significant ($p \leq 0.05$) for total height, bark thickness, branch length, crown depth and stem straightness. Provenance differences within countries were not significantly different ($p \geq 0.05$) for dbh, bole height and root collar diameter. There were significant differences ($p \leq 0.05$) between the provenances for the traits crown spread, leaf length and breadth, fruiting and plant survival indicating a wide range of diversity across the provenances.

There were significant differences in plant height, with provenances from Zimbabwe- Murehwa, Mapanzure and Nyamukwalala attaining the highest height followed by Choma from Zambia while Chimaliro and Litende from Malawi were the shortest (Table 17.4).

Table 17.3. Growth and morphological traits of 12 *Uapaca kirkiana provenances*

Trait	**Region**	**Countries within region**	**Provenance within country**
Total height (cm)	322.95 ± 8.58*	322.26 ± 9. 380*	348.6 ±16.2***
Bole height (cm)	79.66± 3.59*	79.66 ± 3.59***	89.93 ± 6.13 ^{ns}
Dbh (cm)	5.10± 0.097***	5.024 ± 0.152***	5.157 ± 0.238 ^{ns}
Root collar diameter (cm)	6.47 ± 0.133^{ns}	6.75 ± 0.210 ***	8.057 ± 0.336 ^{ns}
Bark thickness (cm)	0.87 ± 0.023*	0.7850 ± 0.037*	0.807± 0.0376 ^{ns}
Crown spread (cm)	2.18 ± 0.049^{ns}	2.15 ± 0.083 ^{ns}	2.2525 ± 0.093 ^{ns}
Crown depth (cm)	2.63 ± 0.061*	2.65 ± 0.126 ^{ns}	2.657 ± 0.126 ^{ns}
Branch length (cm)	52.26 ± 1.38 *	54.43 ± 2.13*	56.45 ± 1.83 ^{ns}
Branchlet length (cm)	21.63 ± 0.962 ^{ns}	21.30± 0.82 ^{ns}	21.88 ± 1.68 ^{ns}
Branch angle (degrees)	51.40 ± 0.902 ^{ns}	55.13 ± 2.30*	44.93 ± 4.39 ^{ns}
Leaf length (cm)	13.763 ± 0.385 ^{ns}	13.11 ± 0.568 ^{ns}	13.85 ± 1.11 ^{ns}
Leaf breadth (cm)	5.86 ± 0.262 ^{ns}	4.80 ±0.312 ^{ns}	5.04 ± 0.57 ^{ns}
Height crown ratio (m)	1.36 ± 0.062*	1.30 ± 0.025 ^{ns}	1.3125 ±0.0304 ^{ns}
Fruiting (1;0)	1.97 ± 0.012 ^{ns}	0.075 ± 0.042 ^{ns}	0.0750 ± 0.0422 ^{ns}
Stem survival (0;1)	2.275 ± 0.085 ^{ns}	2.40 ± 0.195^{ns}	2.475 ± 0.199 ^{ns}
Stem straightness (0-5)	3.45 ± 0.232*	2.27 ± 0.103 ^{ns}	3.395± 0.124 ^{ns}

Table 17.4. Growth and morphological traits of *Uapaca kirkiana* provenance from a 10-year old trial at Makoka, Malawi

Provenance	Ht	dbh	rcd	brth	crd	brcl	brca	strt
Phalombe	359.2 (29.2)	5.25 (0.48)	8.10 (0.712)	0.820 (0.0512)	2.730 (0.279)	58.90 (3.36)	55.0 (0.762)	3.440 (0.277)
Chimaliro	316.1 (30.2)	5.07 (0.524)	7.87 (0.804)	0.870 (0.092)	2.76 (0.204)	65.40 (2.99)	62.10 (2.59)	3.630 (0.217)
Litende	356.6 (43.1)	4.58 (0.470)	7.41 (0.586)	0.770 (0.088)	2.66 (0.319)	50.50 (3.68)	54.10 (2.66)	3.33 (0.297)
Chipata	345.2 (21.0)	3.69 (0.384)	8.21 (0.727)	0.80 (0.081)	2.29 (0.147)	47.40 (3.09)	52.10 (6.91)	3.10 (1.72)
Choma	408.9 (16.1)	5.53 (0.337)	8.83 (0.664)	0.91 (0.070)	2.88 (0.214)	47.60 (2.75)	57.30 (2.18)	3.71 (0.51)
Serenje	314.2 (31.9)	4.11 (0.320)	6.590 (0.501)	0.680 (0.055)	2.350 (0.210)	42.90 (3.52)	49.30 (3.29)	3.050 (0.283)
Iringa	366.0 (23.4)	5.72 (0.465)	8.69 (0.724)	0.860 (0.056)	2.36 (0.196)	45.6 (2.40)	40.20 (6.94)	3.170 (0.203)
Mbeya	348.4 (26.6)	5.200 (0.490)	8.490 (0.654)	1.23 (0.220)	2.950 (0.211)	55.50 (0.274)	60.70 (1.92)	3.61 (0.205)
Mpwapwa	353.7 (17.8)	5.590 (0.368)	9.36 (0.439)	1.0 (0.050)	2.93 (0.169)	54.80 (2.96)	51.60 (6.89)	3.7 (0.132)
Nyamukwalala	359.3 (33.9)	5.20 (0.524)	8.12 (0.821)	0.860 (0.095)	2.35 (0.295)	47.70 (3.55)	49.60 (6.25)	3.04 (0.385)
Mapanzure*	436.4 (37.3)	7.41 (0.639)	10.88 (0.766)	0.850 (0.075)	2.740 (0.362)	51.30 (3.40)	53.10 (6.26)	3.42 (0.389)
Murehwa	440.3 (29.0)	7.18 (0.510)	11.08 (0.666)	0.990 (0.060)	2.760 (0.303)	56.10 (3.63)	59.60 (3.10)	3.480 (0.389)

Ht = total tree height; dbh = diameter at breast height; rcd = root collar diameter; brth = bark thickness; crdp = crown depth; brcl = branch length; brca = branch angle; strt = straightness;* Fruiting observed. The numbers in parentheses are standard errors of the means of traits

Cluster analyses

A dendrogram generated from standardized morphological data suggested three main clusters with a mean genetic dissimilarity of 0.33 (Figure 17.2). The first cluster contained six populations collected from Malawi, (Phalombe, Chimaliro) Zambia (Chipata, Serenje) and Tanzania (Mbeyakyela and Mpwapwa) while the second cluster has provenances from Malawi (Litende), Zambia (Choma), Tanzania (Iringa) and Zimbabwe (Nyamukwalala). Litende provenance from Malawi is genetically closer to Choma from Zambia and Iringa from Tanzania, physically more than 800 km away, than the provenance of Chimaliro in Malawi, physically about 150 km from the sampled Litende site.

Most of the provenances seem to cluster independently from their geographical origin. This is well exemplified in the case of Nyamukwalala, Chimaliro and Iringa provenances that are distantly located but exhibited close clustering distribution. The biplot of principal component analysis (figure not shown) obtained with morphological data sets showed morphological traits specifically total height discriminating some populations by their geographic origin.

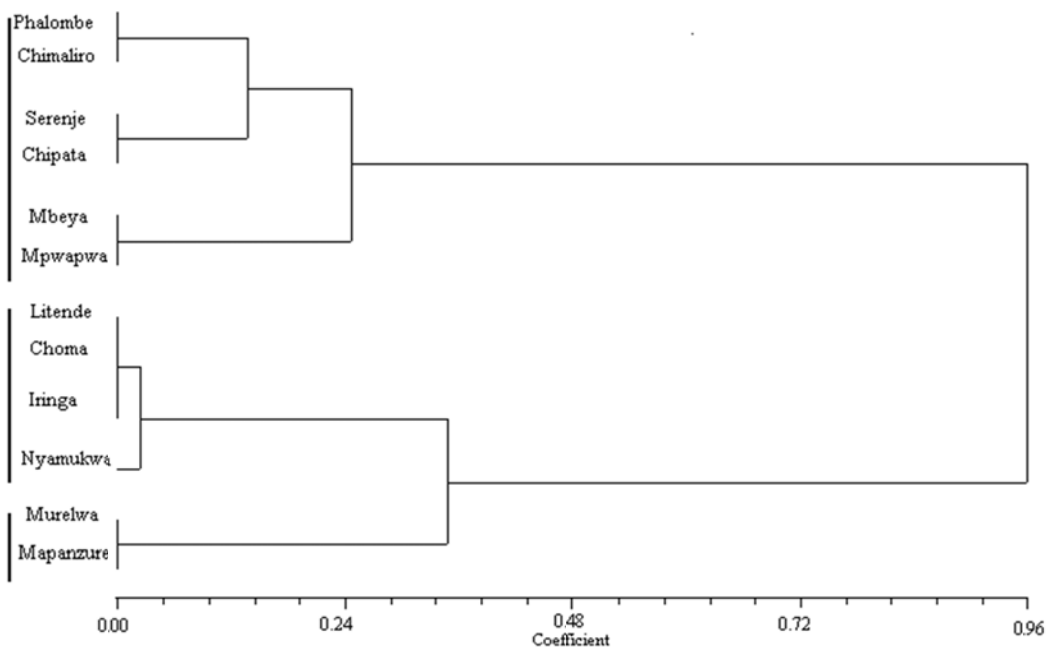

Figure 17.2. Dendrogram of twelve southern African *U. kirkiana* provenances derived from UPGMA from dissimilarity matrix of morphological data

Discussion

The *U. kirkiana* regional provenances grown under the same condition showed varied growth and morphological traits. The geographic source of germplasm for domestication is an important consideration, which in practical application is based on the degree of local adaptation among provenances as well as the cost and availability of material from different areas. Use of local provenance as a germplasm source may ensure better adaptation to the local conditions and reduces transport costs. It is not so clear, how much of the variation can be allotted to differing environmental conditions existing in the locality where seed was collected, it could also be possible that the tested populations represent different ecotypes displaying differenet growth and morphological traits. The pattern of genetic variation along a geographical distribution is confounded by specific local environmental conditions. Apparently, apart from Chimaliro from Malawi, most provenances collected from Zimbabwe (Mapanzure and Murelwa), Zambia (Choma), Tanzania (Iringa) and Malawi (Phalombe) have good adaptive growth traits at the test site in Malawi. Akinnifesi *et al.* (2004b) reported that provenances are more adapted to climatic conditions at their origin, but the pattern and degree of local adaptation varies among species. In this trial, provenance ranking in terms of tree height and diameter was not always consistent with results conducted in Zambia where Chipata and Choma provenances had greatest growth (Akinnifesi *et al.,* 2004b). The good performance of these provenances could be attributed to similarity of the climatic factors, especially rainfall and elevation between the source of the seed and test site. The lack of consistency in the results at the two sites indicates the likely presence of significant provenance and environment interactions, further analysis of results of the regional provenance trials is required to determine the extent of genetic variation in the selection of superior provenances that can perform consistently in diverse climatic conditions.

The provenance groupings accomplished through Unweighted Pair group method of Arithmetic average (UPGMA) were inconsistent with the geographical distribution of the studied provenances. Genetic diversity values for morphological traits ranged from 0.001 to 0.490 which are different from genetic diversity ranges for the same species using molecular markers as reported by Mwase *et al.* (2006). This could reflect the problem of morphological characterisation which is highly influenced by environment and different growth stages. While molecular markers show true expression of the genotype, morphological markers are still very useful in studying adaptive traits. While acknowledging the importance of using local provenance for ecological adaptation, our studies have shown that there is weak evidence that variation in average plant height among populations is associated with environmental gradients. High growth rates observed for provenances from Zambia and Zimbabwe suggest the existence of high variability within provenance which allows the species to adapt to different environments without major genetic alteration.

The UPGMA showed that Mapanzure and Murehwa were distinct, however adaptive growth traits ranked Mapanzure as one of the best provenances and was the only provenance that had started fruiting after 10 years of growth. It is recommended to study the fruit traits since its adaptive and genetic traits differ considerably from the rest of the provenances. Strategies for prioritizing conservation of species diversity should consider the level of diversity as well as the existing threat of populations. The conservation in the different countries must consider the inevitable anthropogenic impacts of cultivation of forest lands on the distribution of genetic variation of the species. The populations with both low diversity and high diversity should be prioritized for conservation to serve as reservoirs of genetic variation and reduce genetic erosion after major changes in the habitat. The identification of moderate genetic variation have important implications for utilization of the species including the development of strategies for improvement of economically important traits such as fruit size, sweetness, colour, number of seeds and growth traits such as time to fruiting.

Conclusion

The existence of higher level of variation within the provenances and moderate to low between provenances suggests a vast genetic base available for selection and tree improvement. The high variation within *U. kirkiana* provenances suggests that sampling from a few populations within a country may capture a large proportion of variation. Nevertheless, sampling from a wide range of provenances among the countries is still advisable as there are significant morphological differences between provenances and countries. Although morphological and growth characterisations are influenced by environment, they can be used hand in hand with molecular markers for revealing adaptive traits and genetic variation. The significant variation in morphological and growth traits in *U. kirkiana* suggests the presence of adaptive genetic variation related to micro-environmental factors and there is great potential to establish high-diversity seed orchards. However when deciding on the most appropriate domestication and improvement strategy for *U. kirkiana*, heritability, vegetative propagation methods and genetic correlations between growth and desirable fruit traits such as time to first fruiting, fruit size, colour, sweetness and pulp ratio should be investigated.

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18. Field Performance of *Uapaca Kirkiana* Muell. Arg (Wild Loquat): Growth and Survival of 8-Year-Old Provenance *Cum* Family Trial Established at Nauko, Machinga, Malawi

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Abstract

The study's objective was to assess phenotypic variation of 8-year-old *Uapaca kirkiana* provenances *cum* families, established in a trial at Nauko using alpha design. Analysis of variance, spearman's rank correlation coefficient and linear regression were employed in detecting relative performance of provenances, assessing correlations between traits, and genecological relations respectively. Significant variations (P<0.05) between and within provenances were observed in height, root collar diameter, number of branches and survival. Phalombe provenance exhibited an outstanding growth performance but poor survival. The study revealed strong positive relationship between height and RCD (r=0.795) and subtle positive relationships between all other traits. Survival was strongly influenced by rainfall (R^2=0.769, P=0.05). The observed variation indicates that there is potential to improve genetic quality of *U. kirkiana* through domestication and selection of superior phenotypes.

Key words: Domestication; *Uapaca kirkiana*; Phenotypic Variation; Genecology

Introduction

Deforestation is reducing species diversity and eroding the genetic base of many tropical trees and leads to lowering the area of productive land (Leakey and Newton, 1994). Domestication of indigenous fruit trees (IFTs) has been identified as one of the avenues to mitigate devastative effects of deforestation, and contribute to socioeconomic development of smallholder farmers (Kwesiga and Mwanza, 1995) *U. kirkiana* was identified through diagnosis and design (D and D) and ethnobotanical surveys as one of the top most priority indigenous fruit tree species of miombo woodlands of southern Africa (Minae, 1995). Studies have revealed great genetic variability both within and between populations of *U. kirkiana* in natural populations (Ngulube 1996, Akinnifesi *et al.* 2005). Extensive planting of the species by farmers is hampered by lack of information on growth performance and survival of *U. kirkiana* in planted stands.

Range wide half-sib provenance trials have been established to identify superior provenances. The study aimed at evaluating growth and establishment of *U. kirkiana* provenances and families established at Nauko in Machinga. Specifically the study examined variations between and within provenances in terms of growth and survival, phenotypic correlations between height, root collar diameter and number of branches but also tested for genecological influence of the original site factors on growth and survival of *U. kirkiana*.

Materials and Methods

The trial was established at Nauko (Table 18.1) in 1997 using alpha design constituting 10 replicates. Data was collected in 2006. Assessed traits include height, root collar diameter (RCD), number of branches and survival percentage.

The data was analysed using GenStat 9th edition (Payne *et al.,* 2006). Unbalanced ANOVA was used to determine differences between and within provenances. LSD was used to separate significantly different treatments ($P<0.05$). Spearman's correlation coefficients were computed between height, RCD, and Number of branches. Simple linear regression was used to detect genecological relationships between provenance performance and ecological factors (Aitken, 2004; Payne *et al.,* 2006).

Table 18.1: study site, provenances, family codes and site factors.

Trial site/Provenance	Family code	Latitude ^{0}S	Longitude ^{0}E	Altitude (m)	MAR (mm)	MAT ^{0}C	Silvicultural zone
Nauko		$15^{0}10'$	$35^{0}23'$	500-1000	840-960	20	C
Phalombe	`1-24	$16^{0}09'$	$34^{0}29'$	900	993	22	C
Dedza	25-51	$13^{0}50'$	$34^{0}18'$	1632	999	18	M
Thazima	52-64	$10^{0}50'$	$33^{0}35'$	1500	1385	18	M
Kasungu	65-71	$12^{0}15'$	$33^{0}50'$	1200	870	20	D
Luwawa	72-90	$11^{0}27'$	$34^{0}01'$	1250	1400	19	J
Litende	91-96	$11^{0}49'$	$34^{0}10'$	1400	975	23	L
Mozambique Bulked	97-100	-	-	-	-	-	-

Results and Discussion

Provenance variation

Variability between provenances in characters such as growth and survival forms the basis of genetic improvement of sexually reproducing organism (Allard, 1960). At 8 years, the provenances showed heterogeneity (even at $P<0.001$) with respect to growth and survival (Table 18.2). Since provenances differ in performance, selection for superior provenances should be done before deciding on germplasm collection. Phalombe provenance showed an outstanding performance in terms of height, RCD, and number of branches. There is need to continue monitoring growth and phenology. If Phalombe provenance will come out as the best in fruit production and quality, then tree breeding in *U. kirkiana* can start at an early stage.

Table 18.2: ANOVA results showing mean height, RCD, number of branches, and survival of *Uapaca kirkiana*.

Provenance	Height, cm	RCD, cm	No. of branches	%Survival
1. Phalombe	3.83 abc (0.05840)	8.89 a (0.1188)	12 a (0.04064)	67.01 abcd (0.01585)
2. Dedza	3.36 abc (0.05431)	8.29 b (0.1104)	11 ab (0.03779)	68.79 abcd (0.01494)
3. Thazima	3.52 ab (0.07338)	8.04 bc (0.1492)	11 ab (0.05107)	79.26 ab (0.02154)
4. Kasungu	3.65 ac (0.10537)	8.07 bc (0.2143)	12 a (0.07333)	70.81 ac (0.02935)
5. Luwawa	3.24 ab (0.06140)	7.49 d (0.1246)	10 bc (0.04265)	76.10 abc (0.01781)
6. Litende	3.15 d (0.11731)	7.47 d (0.2386)	10 c (0.08164)	69.34 ad (0.03170)
7. Mozambique bulk	3.23 d (0.13363)	7.78 cd (0.2718)	9 c (0.09299)	74.90 e (0.03882)
LSD	0.2469	0.5022	0.17	0.06954
Mean	3.43	8.00	3.26	0.93
CV	28.31	24.50	20.62	0.06954

-Values followed by the same letter(s) in the column indicate no significant variation at 5%; -Numbers in brackets are standard errors

Within provenance (family) variation

Family variation indicates the genetic structure of the population. Selection at family level provides greater gains (Kanowski and Barralho, 2004). It is based on the premise that when a greater number of individuals contribute to the family mean, the mean phenotype value approximates closely the mean genotypic value (Lerner, 1958 cited in Nkaonja, 1975). The study revealed significant variations between families (Table 18.4). Significant family differences exist within Phalombe, Dedza, Luwawa, Litende and Mozambique Bulked provenances. No significant differences were detected within Thazima and Kasungu provenances indicating subtle family variation in the assessed traits at 8 years of age. Table 18.3 shows superior families. Some families are superior in more than one trait. The best families should be monitored if they are going to maintain superiority.

Table 18.3: Best performing families/treatment codes (in descending order) in terms of height, root collar diameter (RCD), number of branches and survival

Provenance	Family/treatment codes			
	Height	**RCD**	**Branches**	**Survival**
Phalombe (1-24)*	3, 6 , 8 , 3 , 12 , 9 , 11 , 2 , 24		10 , 6 , 15 , 17 , 23 , 3 , 19	
Dedza (25-51)	44 , 32 , 46 , 36 , 43 , 39 , 41 , 25	32 , 33 , 43 , 46 , 40 , 44		25 , 35 , 51 , 34 , 39 , 42
Thazima (52-64)				
Kasungu (65-71)				
Luwawa (72-90)	88 , 80 , 78 , 77 , 82 , 73		89 , 83 , 77 , 79 , 80 , 87	
Litende (91-96)	93 , 96 , 95			
Mozambique bulked (97-100)	100 , 99	100 , 98	100 , 99	

*Values in brackets are range of families/treatment codes used

Correlation between height, RCD and Number of branches

Strong positive relationship between height and RCD (Table 18.5). The strong positive correlation between height and RCD is of significance in index selection. Barrett and Fried (2004) observed that height is a highly heritable trait and correlates well with other metric traits and thus have been generally used as an index in selecting superior trees or stands. Strong positive correlation between height and RCD as already alluded to above is of significance in index selection. Height can be inferred from root collar diameter measurements thereby reducing operational costs. Height of trees, especially of broadleaved with deliquescent canopy, is difficult to measure hence measurement of RCD would ease the work and increase precision.

Table 18.4: Mean squares analysis of variance of family within provenance variation in terms of height, root collar diameter (RCD), number of branches and survival.

Provenance (family/treatment)	Source of variation	D.F	Height	RCD	Number of branches+	Survival+
1. Phalombe (1-24)	Replicate	4	30.2855***	121.367***	7.4201***	121.367***
	Family	23	1.6253**	9.421	0.6904*	9.421
	Residual	255	0.7801	6.989	0.4447	6.989
2. Dedza (25-51)	Replicate	4	21.0623***	93.172***	4.2937***	93.172***
	Family	26	1.8349***	7.558**	0.5762	7.558**
	Residual	296	0.8380	3.916	0.4624	3.916
3. Thazima (52-64)	Replicate	4	23.8218***	106.693***	8.5142***	106.693***
	Family	12	0.9414	3.358	0.3693	3.358
	Residual	162	0.7107	2.753	0.4122	2.753
4. Kasungu (65-71)	Replicate	4	7.5107***	21.141***	2.2847***	21.141***
	Family	6	0.5257	2.525	0.8072	2.525
	Residual	76	0.9939	3.166	0.3881	3.166
5. Luwawa (72-90)	Replicate	4	20.0091***	75.807***	5.16***	75.807***
	Family	18	1.8405*	5.353	0.825*	5.353
	Residual	234	0.9142	3.668	0.4708	3.668
6. Litende (91-96)	Replicate	4	3.020*	23.373***	2.5546***	23.373***
	Family	5	3.670*	8.365	0.5117	8.365
	Residual	60	1.134	3.774	0.4053	3.774
7. Mozambique bulk (97-100)	Replicate	4	5.786***	18.309***	0.05442***	18.309***
	Bulked seedlot	3	6.32**	10.807*	0.18358*	10.807*
	Residual	46	1.094	3.242	0.05342	3.242

* significant at P ≤ 0.05; ** significant at P ≤ 0.01; *** significant at P ≤ 0.001; + value in the transformed state

Table 18.5. Correlation between height and root collar diameter

	Height	**RCD**
RCD	r=0.789 P<0.001	
branches	r=0.594 P<0.001	r=0.576 P<0.001

Genecological correlations

Provenance-site matching is critical for a tree to grow to its full potential (Zobel and Talbert, 1984). Performance of individuals of a tree species depend jointly on the location where seed was collected and the environment in which the resulting seedling is planted (Zobel and Talbert, 1984; Aitken, 2004). Maladaptation can result in slow growth, and injury or mortality due to biotic or abiotic agents. Simple linear regression analysis revealed significant genecological associations between root collar diameter and latitude (P=0.035); survival and longitude (P=0.008); and between survival and rainfall (P=0.022) (Table 18.6). Rainfall could be taken as the most important factor that influences survival of *U.* kirkiana provenances established in Nauko.

Conclusion

In this study there was strong evidence against the hypothesis that *Uapaca kirkiana* provenances and families are not significantly different. The results at 8 years in the field have revealed that there is genetic variability between provenances and between families within the provenances of *U. kirkiana* established at Nauko.

Strong correlations exist between root collar diameter and height. Number of branches showed frail relationship with other traits.

In this study Phalombe provenance maintained its superiority in terms of height growth, root collar diameter growth and number of branches. However it had the poorest survival of all provenances. Mozambique bulked provenance lagged behind in terms of growth. If Phalombe provenance will come out as outstanding provenance in fruit quality and production, then index selection can be done at early stage in *U. kirkiana* tree species.

From the findings it came out clear that growth of *U. kirkiana* populations is influenced by the origin site factors. This provides a justification for selection of the right provenances for afforestation programmes. The important environmental gradients responsible for this variation appear to be rainfall and latitude.

These results are not enough to infer that provenances showing fast growth should be recommended for domestication but can forms the basis for selection. If this early variation and superior performance will be related to traits of economic value, then selection of high productive provenances and families can be done at an earlier stage.

Table 18.6: Summary of regression analysis for survival, growth and provenance origin-site characteristics

Dependent variable Y	Independent Variable X	α (constant)	β_1 (slope)	P-value	Coef. of Determination (R^2)	Std. error of R^2	Adjusted R^2
Height	Longitude	-2.400	0.172	0.279	0.361	0.643	0.201
	Latitude	2.455	0.0788	0.207	0.059	0.230	-0.000
	Altitude	4.457	0.000326	0.085	0.080	0.190	0.455
	Rainfall	3.810	-0.00032	0.587	0.002	0.276	-0.000
	Temperature	3.360	0.005	0.939	0.564	0.287	-0.000
Root collar diameter	Longitude	-21.10	0.857	0.220	0.334	0.481	0.167
	Latitude*	5.133	0.2286	0.035	0.711	0.320	0.638
	Altitude	9.630	-0.00118	0.230	0.345	0.485	0.182
	Rainfall	8.890	-0.00083	0.487	0.127	0.555	-0.000
	Temperature	8.01	0.002	9.989	-0.000	0.594	-0.000
Survival %	Longitude*	482.2	-12	0.008	0.216	2.030	0.200
	Latitude	96.14	-1.906	0.064	0.617	3.290	0.521
	Altitude	60.50	0.00849	0.353	0.854	4.710	0.817
	Rainfall*	51.78	0.01824	0.022	0.769	2.560	0.711
	Temperature	99.30	-1.37	0.204	0.365	4.240	0.206
No. branches	Longitude	-38.70	1.46	0.290	0.438	0.976	0.297
	Latitude	5.670	0.41	0.064	0.618	0.706	0.523
	Altitude	14.38	-0.00259	0.152	0.270	0.857	0.080
	Rainfall	13.59	0.00245	0.260	0.300	0.956	0.125
	Temperature	10.31	0.029	0.991	0.003	1.140	-

**Significant relationship (P<0.05)*

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19. The Contribution of Indigenous Fruit Trees in Sustaining Rural Livelihoods and Conservation of Natural Resources Around Mwekera Area, Zambia

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Abstract

The dependency of many African rural households on natural resources for sustenance is widely acknowledged. The utilization and commercialization of indigenous fruit trees (IFTs) has in the past been overlooked by extension agencies due to the misconception that they do not play a major role in contributing to the rural livelihoods. There is new and increasing emphasis on the contribution of indigenous fruit trees (IFTs) on improving rural livelihoods in the *Miombo* woodlands. A study was conducted in Mwekera area in Zambia using participatory rural appraisal techniques to ascertain the significance of IFTs in the livelihoods. The study revealed that 97 per cent of the respondents collect indigenous fruits and ranked in order of importance *Uapaca kirkiana*, *Anisophyllea boehmii* and *Parinari curatellifolia.* The study has revealed that 46% of households process the fruit into juices and/or porridge. Furthermore IFTs are also used as traditional medicine. Sixty three percent (63%) of the households used IFTs for medicinal purposes with two-thirds of the respondents citing *Anisophyllea boehmii* as an important medicinal tree species. The study also showed that 85% of the respondents have seen a change in the forest cover resulting into loss of biodiversity with the respondents indicating that the change is with respect to reduction in forest size and scarcity of some species. Fewer trees mean less forest derived foods and medicine for the local people. It is concluded that IFTs have both food and non-food value to the local communities and are hence significant in sustaining households.

Key words: Indigenous fruit trees (IFTs), rural livelihoods, processing, food security, biodiversity, miombo woodlands

Introduction

Most of the rural people in southern and eastern Africa are food insecure and chronically malnourished (Tiisekwa *et al.,* 2004). Natural resource based livelihood strategies and migration are therefore common in rural areas as hunger escaping opportunities. Rural people therefore use various products from their environment in order to sustain their livelihood. According to Scherr (1995), rural households' survival strategies encompass multiple objectives in maximization of utility, like provision of food and subsistence goods, cash for purchase of goods and services and saving for future needs. Households therefore depend on various activities to sustain their livelihoods.

In southern Africa, the fruits play an important role especially during times of famine (Akinnifesi *et al*., 2008) providing an alternative source of nutrition (Muok *et al.,* 2001); and as a source of cash income (Akinnifesi *et al*., 2006). Despite this significance of IFTs in livelihoods as highlighted by various authors (Akinnifesi *et al*., 2008; Akinnifesi *et al*., 2006; Tiisekwa *et al.,* 2004), Muok *et al.* (2001) reports that there is however little information available on specific communities' actual use, management and preferences in this regard. The study's aim was to fill this gap by investigating the utilization of IFTs in Mwekera rural livelihoods.

Materials and Methods

The purpose of the research involved both exploration and description. The explorative part of the research was addressed by using Participatory rural appraisal techniques which comprised of group meetings, transect walks, seasonal calendar of activities. This was complemented by descriptive research, in the form of individual in-depth interviews, and a household survey. . A total of 70 households in Mwekera area in the Copperbelt province of Zambia. Data was analyzed using Statistica 7.1statistical package to generate descriptive statistics. The generated statistics tables and associated graphs were used in the interpretation of the results. Information obtained from the group interviews was analyzed at the spot by recording consensus conclusions from the participants. The purpose of these meetings was to support the validity of the information obtained from the analysis of the questionnaire.

Results and Discussion

Woodland use and seasonality

From the participatory rural appraisal it became clear that the woodlands in the study area are important to the rural households. They are a source of energy, i.e. as fuel wood, as well as a source of medicine, building poles, thatching grass, fibre, wild vegetables, grazing grass, mushrooms and wild fruits (see Table 19.1). These woodland products can be classified as either seasonal or perennial. Products are classified as seasonal if they are gathered from the woodlands only during some months of the year, while perennial products are those that are gathered throughout the year. Among the seasonal products are wild fruits, wild vegetables, mushrooms and thatching grass. The other products from the woodlands, i.e. fuel wood, medicines, fodder, building poles and fibre, are perennial (see Table 19.1).

Food security of households

The levels of food insecurity are high in rural areas. According to the survey, 99% of the households suffer from food insecurity. The months with the least food reserves are between November and April. This period has therefore been termed 'hunger period'. Akinnifesi *et al.* (2004) reported that between 60-85% of rural households in southern Africa lacked access to food for three to four months each year. The situation is worsening due to erratic rainfalls (Akinnifesi *et al.,* 2008) which results in poor harvests which lasts only for a few months.

Fruit collection and processing

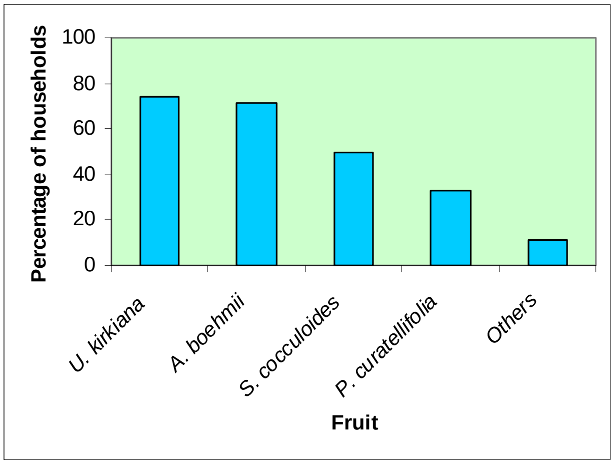
The people in the study area have access to various indigenous fruit trees. The IFTs were not only found in the woodland, but some households retained fruit trees on their fields, by leaving trees standing in agricultural land. Almost all of the respondents (97%) in the household survey indicated that their households collect fruit. The preference ranking revealed that *U. kirkiana, A. boehmii and S. cocculoides* as the top ranked species respectively (see Figure 19.1)

A breakdown of the kinds of fruit collected showed that 74 % of the households collect *U. kirkiana*, 71% collect *A. boehmii*, 50% collected *S. cocculoides*, while 33 % collect *P. curatellifolia*). In addition to these fruit that are collected by a large proportion of the households, 11% of them also reported collection of *L. kirki*, *S. pungens*, *S. guineense*, *G. huillensis* and *D. mespiliformis* (Figure 19.2).

It's evident that indigenous fruits are an important source of food to the households. Indigenous fruit therefore help to provide food security to rural households. The findings of this study are in agreement with various studies (Muok *et al.,* 2001; Maghembe *et al.,* 1994; FAO, 1983; Fashawe, 1972) that have reported the importance of indigenous fruit as a dietary supplement. Akinnifesi *et al.* (2006) reported that indigenous fruits are important in the Southern Africa Development Community (SADC) especially for marginalized groups in society. It has further been reported that indigenous fruits contribute on average about 42% of the natural food basket that rural households rely on in southern Africa (Akinnifesi *et al.,* 2006; Campbell *et al.,* 1997).

Table 19.1: The seasonality of forest product use

Forest Products	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	**Dec**
Fuel wood	■	■	■	■	■	■	■	■	■	■	■	■
Charcoal	■	■	■	■	■	■	■	■	■	■	■	■
Building poles	■	■	■	■	■	■	■	■	■	■	■	■
Fibre	■	■	■	■	■	■	■	■	■	■	■	■
Wild fruits	■	■							■	■	■	■
Medicines	■	■	■	■	■	■	■	■	■	■	■	■
Thatching grass				■	■	■	■	■				
Fodder	■	■	■	■	■	■	■	■	■	■	■	■
Mushroom	■	■										■
Wild roots	■	■	■	■	■	■	■	■	■	■	■	■
Wild vegetables	■	■							■	■	■	■



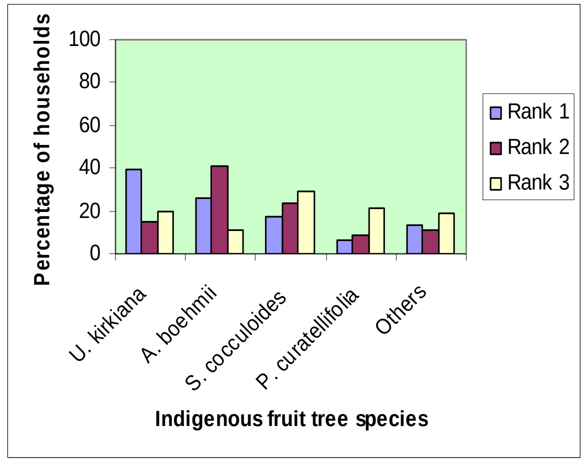


Fig 19.1: Preference ranking of IFTs (n=70) **Fig 19.2:** Fruit collected by households (n=70)

Rural household process fruit, with 46% of the households reporting processing fruit into juices and/or porridges. Processing of fruit is limited to a few fruit tree species such as *Uapaca kirkiana, Anisophyllea boehmii* and *Parinari curatellifolia*. The proportions of households that process each of these species in descending order are: *Anisophyllea boehmii* (36%), *Parinari. curatellifolia* (33%), and *Uapaca kirkiana* (31%). There was no evidence of commercial processing of any fruit. The household survey results reveal that all the households in the study area that process fruit do so for home consumption. The essence of processing is to add value to, and increase the palatability of the fruit. Processing of fresh fruits is necessary, as the fruits' perishability rate is very high, due to lack of cold storage facilities in the rural areas.

It may be argued that the local people are also unaware of the processing technologies that may be appropriate to their needs, despite the fact that technologies are being used elsewhere in Zambia and southern Africa. Several studies (Packham, 1993; Kwesiga and Mwanza 1995; Mateke *et al.*, 1995; Leakey, 1999; Saka *et al.*, 2004; Akinnifesi *et al.*, 2006) have highlighted the processing of IFTs into wine and jams by various groups, communities and small-scale enterprises, yet the information regarding this processing, which is very valuable to communities that utilize IFTs, is lacking in many communities. For example, Leakey (1999) reported that in Zambia, *U. kirkiana* was processed into local potent spirit *kachasu,* jams and cakes. Similarly, Akinnifesi *et al.* (2006) highlighted the processing of *U. kirkiana* into *masuku* wine and jam in Zambia while Parinari nuts were processed into oil in Zimbabwe and Strychnos fruits into juice in Tanzania.

These fruits that are processed are available in the study area. This provides some evidence that in the area studied, the people probably have limited knowledge on the processing of indigenous fruit. Ham (2003) argued that the development of improved indigenous fruit processing technologies owed its effectiveness to the information being disseminated to communities who can use it in their everyday lives

Tiisekwa *et al* (2004) stressed that if farmers in areas of fruit tree availability are trained, they can easily process the fruit during the fruiting season for home consumption during the off-season and for sale to earn cash. Thus the IFTs can contribute to improving the food and nutritional security of rural people.

Indigenous fruit harvesting

The study showed that rural people use various fruit harvesting methods. Fruit harvesting is done by knocking the fruit down with sticks, throwing objects to dislodge fruit, shaking the stem or branches, climbing the trees, and picking fruit up from the ground following abscission. Poor harvesting methods cause some fruits to sustain bruises, thereby reducing the fruit's shelf life. These results are similar to those of an earlier study by Kadzere *et al*. (2004), who reported that some harvesting methods can cause damage to the fruit trees and excessive bruising of the fruit. The main injuries that the fruits sustain are abrasion injuries, impact injuries and compression injuries. The group interviews revealed that the indigenous fruits that are affected mostly are *Uapaca kirkiana* and *Anisophyllea boehmii*, due to their delicate outer covering when the fruit is fully ripe. In an attempt to reduce post-harvest losses of fruit, the local people use baskets called *museke* to transport *U. kirkiana* and *A. boehmii.* The *museke* allows the air to circulate through thereby avoiding fruit rot. The fruit that are very ripe are more susceptible to damage than those that are less ripe. To avoid these damages, some rural people prefer harvesting fruit that are not yet fully ripe.

In the study area, it's evident that the harvesting methods currently practiced cause some fruit losses. These considerable losses of fruits reduce the quantity and quality of fruit available for consumption and sale. These findings correspond to that by Saka *et al.* (2004) who reported that fresh fruit incur direct or indirect nutrient and general quality loss from the field to the consumer. In quantifying the amount of fruits lost, Wilson (2002 cited in Hughes and Haq 2003) reported post-harvest losses of fruit to be between 40 and 60%. Kordylas (1990) estimated post-harvest fruit loss to be 5-25% in developed countries compared to as much as 20-50% in developing countries. These losses are attributed to a lack of knowledge in fruit handling and marketing.

Constraints to sustainable harvesting

The absence of rules regarding the harvesting of IFTs is a constraint to sustainable usage. This study has revealed that there are no norms, either community-based or traditional, on harvesting of IFTs in the study area. In open areas, the forest resource is viewed as a common property. The free access and consequent exploitation of common resources has been termed by Hardin (1968) as the 'tragedy of common'. This is because unrestricted demand for a finite resources causes exploitation of the resources (Bromley and Cernea, 1989) as each individual's aim is to maximise his/her own benefits. This might be attributed to the fact that there are no incentives to act in a socially altruistic way (Hardin, 1968). It is therefore necessary to come up with IFTs policies that will empower community groups to manage the IFTs in open areas.

Fruit collection responsibilities

Collection of fruit is predominantly conducted by women and children. They account for over 80% of fruit collectors. Women combine fruit collection with other daily activities such as collecting fuelwood, cooking and daily chores. This study confirms what other studies have reported on women as being the primary fruit collectors (Ruiz-Pérez *et al*., 1997; Schreckenberg, 2004). In Benin, the shea tree (*Vitellaria paradoxa*) is considered 'a gift from God to enable women to survive' (Schreckenberg 2004) because of its importance with respect to providing income to women through trading. Similarly, Ruiz-Pérez *et al*. (1997) reported that women were the major collectors and decision-makers with regard to the selling of indigenous fruits.

Medicinal value of IFTs

It has been reported by Mander and Le Breton (2006) that up to 80% of the world's population (mostly in developing countries) rely on traditional medicine for primary health care. The survey on the value of IFTs specifically for medicine showed that 63% of the households use IFTs for medicinal purposes. *Anisophyllea boehmii* was the most used IFT (67 %) followed by *Uapaca kirkiana* (44 %) and *Parinari curatellifolia* (36%). See Figure 19.3. The tree parts that are used are usually the roots, leaves and bark. Extraction of the active drugs from barks and roots is usually done by means of the processes of infusion and decoction. The use of indigenous trees for medicine is widespread probably due to poor health services which are often not stocked with drugs. Traditional medicine is preferred as the local people consider it to be effective. The knowledge about the medicinal use is passed through generations. The plant parts that are used are leaves, barks and roots. Tree barks are harvested using axes, while roots are harvested using hand hoes.

Deforestation

It was found that 85% of the respondents have seen a change in the forest cover in the past 10 years. According to the respondents, the forest cover is diminishing, and it is becoming difficult to find certain species of trees in the forest. The loss of forests cover is attributed to charcoal production and expansion of land for agriculture. Seventy-four per cent (74%) of the respondents cited charcoal production and clearing of forest for agriculture as the main causes of forest loss.

Impact of forest loss on availability of IFTs

The loss of forest cover also entails a reduction in the forest tree species distribution. By far the majority (93%) of the respondents in the household survey indicated that indigenous fruit trees are under threat, as they report a reduction in their availability. Respondents also mentioned that the distance that people have to cover to collect fruit has increased over time. The fruits have become scarce, particularly in the nearby forest and open areas . A breakdown of the threatened IFTs species as indicated by the respondents is *Uapaca kirkiana* (38%) , *Anisophyllea boehmii* (38%), *Parinari curatellifolia* (21%), while only a small proportion of respondents (3%) reported *S. cocculoides* as being threatened. These finding are supported by Hyde and Seve (1993), who reported that *Uapaca kirkiana* is under threat of extinction in the *Miombo* due to high rates of deforestation, which has been compounded by little domestication (Ngulube *et al.,* 1995). It is important to note that the IFTs that are highly preferred by the households are the ones that were identified as being under threat of extinction. The change in the forest cover as reflected in the, reduction in forest size and scarcity of some species has repercussions on rural households which are highly dependent on forests. Fewer trees means less forest derived foods and medicine for the local people whose livelihoods significantly depend on forests. The people are forced to migrate to new areas, causing further deforestation and land degradation in the new areas.

Agricultural expansion or the practice of shifting cultivation is known to contribute to huge annual losses of forest cover (Chidumayo, 1997; PFAP, 1998). People clear the forest to make way for agriculturally based land use systems, which rely on the forest as a source of nutrients. The practice of slash-and-burn agriculture helps to release nutrients that are held in the plant components of the ecosystem. The released nutrients improve the soil for a short while. Once the nutrients are exhausted, people shift their clearing practices to a new forest area, in search of fertile soil. The increase in human population poses a challenge to this form of cultivation.

Charcoal production also contributes to loss of biodiversity. The problem of charcoal production is prevalent in areas closer to urban centres (SNR, 2005). The high deforestation in the vicinity of urban areas is attributable to the high energy demand in these areas. Rural areas in the vicinity of urban areas meet this high demand by supplying charcoal. Due to the high electricity tariffs, most urban households use charcoal to meet part or all of their domestic energy demands, making charcoal a major household fuel in urban Zambia (Chidumayo 1997). With regard to the study area, the demand for charcoal in Kitwe is also high, providing a ready market for charcoal.

Domestication of IFTs

In order to improve the contribution of the IFTs to the rural household livelihoods, it is vital to domesticate IFTs. Local planting, product development and market expansion are the first steps in domesticating wild fruits in fields, homesteads and communal areas (Maghembe *et al.,* 1998; Leakey *et al.,*1994; Akinnifesi *et al.,* 2006). The choice of which trees to domesticate follows a priority setting which identifies the most highly valued species. Domestication is likely to be effective when local people are involved in the process of priority setting of the tree species (Franzel *et al.,* 1996). There is therefore need to promote domestication of IFTs in the study area, and the trees that should take preference are those that are highly ranked by households, and were reported to be under threat. It is cardinal to consider domesticating the IFTs that are scarce, so as to maintain and broaden biodiversity. It is worth observing that the trees that are under threat are actually the same fruit trees that are ranked highly, i.e., *U. kirkiana* and *A. boehmii*. Domestication of IFTs is important as the indigenous fruit trees are vital for the survival of rural households as they provide food, medicines and are source of income.

Conclusions and Recommendations

Indigenous fruits are important sources of food, income and medicines, which are vital in sustaining rural communities. *Uapaca kirkiana, Anisophyllea boehmii* and *Parinari curatellifolia* are the most preferred species, due to their contribution as a food supplement to the households, and because of their marketability. The rates of deforestation in the area are high and have caused a reduction in the availability of IFTs. As regards to processing, most of the processed fruits are for household consumption. Although there was knowledge on the processing of some indigenous fruit, there was an obvious lack of information on processing of fruit into commercially viable products such as wines and oils. The following recommendations are drawn from this study:

1. Domestication of indigenous fruit trees and restocking of natural forests with IFTs.
2. In order to improve the processing and marketing of IFTs, the rural community must be provided with information on harvesting, use and processing as well as regular marketing information on the potential fruit markets. The government and stakeholders must link the rural fruit producers with possible markets including international markets.
3. The reproductive biology and ecology of *Anisophyllea boehmii* must be investigated in order for its domestication to be initiated.

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20. The Role of Forest Resources in The Strategies of Rural Communities Coping with the HIV and AIDS Epidemic in Africa

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Abstract

The HIV pandemic is deeply entrenched in many countries in Africa and has had dramatic effects on rural livelihoods. In poor rural communities only a few people have access to treatment due to high prices of conventional medicine, poor health infrastructure and long distance to the health centers. The combination of the high incidence of HIV-related illnesses, high cost of treatment and the scarcity of health services in the rural areas have led to a greater dependence on the natural resources. Forest products are easily accessible to most people and their use has increased over the years. The higher mortality rate of adults has increased the demand for wood, in part to prepare food for increasingly frequent funerals, among others. The impact of HIV and AIDS on household labour has intensified the dependence on forest food products. This paper examines the role of forest resources in response to HIV and AIDS, particularly in terms of food, herbal medicines and energy. It is based on the findings of different case studies that have been carried out in different parts of Africa over the years. The paper shows that HIV and AIDS epidemic has increased the dependence of communities on forest resources and that the pandemic has environmental and natural resource management implications. Some forest policies and programme interventions that might help lessen the impact of the pandemic on natural resources and the role forestry can play in the multi-sectoral response to HIV and AIDS have been highlighted.

Key words: HIV/AIDS, Forest resources, Non wood products

Introduction

Since the emergence of the Human Immunodeficiency Virus/Acquired Immune Deficiency Syndrome (HIV/AIDS) epidemic in the early 1980s, more than 60 million people worldwide have been infected by HIV and over 20 million have died from AIDS. In 2004 alone, the global HIV/AIDS epidemic killed more than 3.1 million people, and an estimated 4.9 million acquired the HIV bringing to 40 million the number of people living with the virus around the world (UNAIDS, 2005). The AIDS-related excess mortality has had a profound impact on the demographic composition of communities and households and sub-Saharan Africa (SSA) has been the hardest hit region of the world (UNAIDS 2003). By 2010, AIDS is projected to leave 20 million African children under 15 years of age without one or both parents (UNAIDS and WHO, 2002).

In sub-Saharan Africa, natural resources (i.e., forests, woodland savannas, coastal mangroves, etc.) serve as a safety-net for rural households coping with agricultural shortfalls, consistently providing income and food security for the rural poor, and supplying medicinal plants on which traditional healthcare systems depend on. It has been established that HIV/AIDS constrains agricultural productivity, reduces household wealth and food security, and increases demand for healthcare but the relationships between these impacts and natural resources have been overlooked in the analysis of HIV/AIDS (FAO, 2003). Households and communities afflicted by HIV/AIDS depends on natural resources and failure to understand these relationships will limits the development of multi-sectoral interventions that build-on and support local responses to HIV/AIDS.

For a long time, HIV/AIDS has been viewed purely as a health issue, yet HIV/AIDS has implications that reach far beyond health - including great impacts on natural resources, agriculture and food production systems. In its earlier stages, the HIV/AIDS epidemic was predominantly an urban problem, affecting more men than women, and those with relatively higher incomes. Now the epidemic has rapidly moved into the rural areas, hitting those who are least equipped to deal with its consequences. In SSA, most infected people live in the rural areas and HIV/AIDS has become mostly a rural problem (UNDP, 2002). With its largely rural-based economies, it is unlikely that the epidemic in sub-Sahara Africa can be controlled without the effective support to natural resources and agricultural sector (du Guerny, 1999). This sector is in a strong position to assist in both the prevention and mitigation of HIV/AIDS (Gari and Villareal, 2002).

Forests and other tree products continue to constitute an important component of household health and nutrition in Africa - a continent with a forest cover of 21 percent (Hoskins 1990; Ssene, 2000; FAO, 2001). Though undervalued by planners and policy makers (Katerere 1998), forests and trees provide food, fibre, fodder, fuel, and medicinal products (Nair, 1990). Neglecting to adequately recognize these values of forests, forest policy - or the lack thereof, often denies the socio-economic benefits of forests to those who are dependent upon them (Dewees, 2000). Africa's forests are being converted at a rate of nearly 1 percent annually, the highest of any region in the world (FAO, 2001). Marginalization of forestry within policies external to the sector, such as agriculture, is one of the major constraints to sustainable forest management (FAO, 1996; Mlay *et al.,* 2000). Mainstreaming forest policy in socially sustainable national development programmes requires further efforts to quantify the non-timber services rendered to society at large, as well as recognition of these values by both foresters and planners outside of the forest sector (such as agriculture and health). There is therefore need to recognize forest based households activities which are vital to food security in Africa and which cannot be sustained if HIV/AIDS continues unchecked. Where availability or affordable access to food is lacking, the prevalence of HIV is also alarmingly high. This unfolding tragedy underlines the need to tackle rural development, food security and agriculture policies in concert with fighting the AIDS epidemic. The role of forests and woodlands becomes therefore very relevant in helping the communities in rural areas to cope with HIV/AIDS in SSA.

The challenge of HIV and AIDS to sustainable development in Africa

In Africa, HIV/AIDS is undermining progress towards sustainable development, leading to environmental exploitation and reversing many of the development gains of recent decades. By the end of 2006 there were an estimated 39.5 million adults and children living with HIV/AIDS, 24.7 million (63%) of whom are in SSA. Of the estimated 4.3 million new infections and the 2.9 million deaths from HIV/AIDS in 2005, 2.8 million (65%) and 2.1 million (72%) respectively were adults and children living in SSA (UNAIDS, 2006). One of the major causes is the desperate poverty and inequality experienced in some communities and countries. Poverty is a driver of HIV/AIDS and HIV/AIDS is a driver of poverty. It is a vicious circle. Where people are deprived of adequate health services, access to information about HIV prevention, and adequate nutrition and food security, conditions are set for HIV/AIDS to spread very rapidly (Oglethorpe and Gellman, 2004).

HIV/AIDS is devastating people's lives and livelihoods, resulting in damaging environmental impacts. Desperate people are more concerned with meeting immediate needs through short-term environmental exploitation than with long-term sustainability. The environmental impacts are diverse and a cause for concern because surviving children, grandparents and spouses still have food and livelihood needs but must satisfy them from an increasingly impoverished resource base. A major environmental impact is that HIV/AIDS-affected families and communities tend to increase exploitation of local environmental resources. The need for alternative incomes in response to the loss of family breadwinners is leading to unsustainable levels of hunting, fishing, fuel wood gathering and charcoal production for income generation.

As shown in Table 20.1, HIV/AIDS have serious impact on national economies and it is estimated that labour in the ten worst affected African countries will decrease by 26% over the next 20 years (FAO, 2001).

Table 20.1: Projected Loss in Total Population and Agricultural Labour Force Due to AIDS, 1985-2020 in Some SSA Countries (Source: FAO 2001)

Country	Total Population	Agricultural labour force
Namibia	-17%	-26%
Botswana	-30%	-23%
Zimbabwe	-23%	-23%
Mozambique	-16%	-20%
South Africa	-27%	-20%
Kenya	-16%	-17%
Malawi	-17%	-14%
Uganda	-8%	-14%
Tanzania	-7%	-13%

Impacts on the agricultural sector are also grave, with dire implications for future local and national food security. It is estimated that around 7 million agricultural workers have died from AIDS since 1985 in the 25 most severely affected African countries, and that a further 16 million more could die from the disease in SSA within the next 20 years (UNAIDS, 2002). This will have devastating impacts on developing country economies and food security, especially the lives, livelihoods and food security of rural families and farming communities. Some countries in Sub-Saharan Africa like Botswana, Namibia and Zimbabwe are expected to have a deficit of more than 20% in their agriculture labour force by year 2020 (Table 20.1). This will have a big impact on national economies taking into consideration that most of SSA are agricultural based. HIV/AIDS epidemic is also undoing the progress made in life expectancy in SSA which would have been 62 years without HIV/AIDS but has now dropped to just 47 years (DFID, 2004). It is predicted that it may fall below 30 years by 2010 if current AIDS trends continues in Africa (DFID, 2004). HIV/AIDS is also undermining sustainable resource use and environmental conservation.

Desperate people have few choices and they have neither the reason nor the ability to fulfill long-term objectives but instead they are concerned with meeting immediate short-term needs for food, energy, water, medicine and incomes. This results in excessive exploitation of resources as a survival mechanism, breakdown of community sustainability activities, lack of maintenance of conservation infrastructure such as for soil and water and lack of time and resources to implement long term projects such as establishing woodlots. This exacerbates resource scarcity and food insecurity. Households headed by grandparents, women and children are becoming increasingly common (Figure, 20.1). The impacts are undermining food, nutrition and income security, thereby pushing surviving people into livelihood strategies that may make them more vulnerable to contracting HIV themselves. One of the most critical characteristics that makes HIV/AIDS unique from other illnesses is that it disproportionately affects the most productive people in society, the very people on whom so many others depend. The most affected age group is 15-49 years which consists of breadwinners in society and the people who the children and extended family systems depending on.

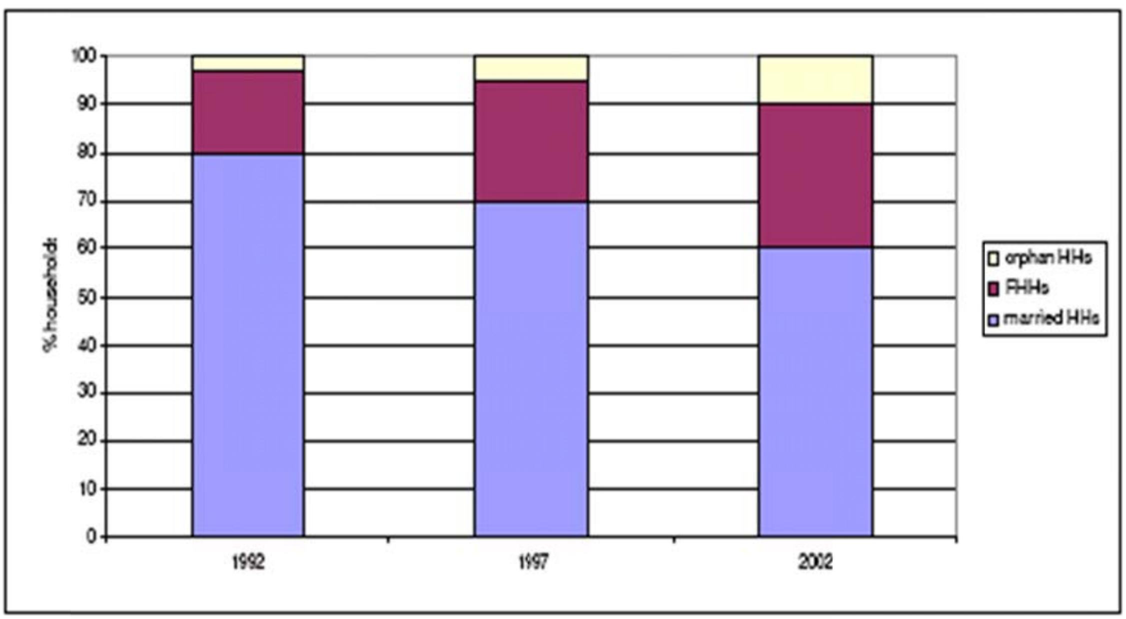

Figure 20.1. Changing Composition of Households in Bondo District, Kenya, 1992 to 2002

Role of forests in mitigating HIV and AIDS

Forest ecosystems contribute to the diets and subsistence of forest dwellers. In increasingly market-oriented economies, they provide a significant portion of the food and medicines consumed by urban populations. Recognition that the sustainable use of forest resources is essential for local livelihoods and the well-being of national population can provide a foundation for investment in conservation of forest biodiversity and its integration with objectives of poverty reduction, food security and disease reduction in development policies. Forest biodiversity is indispensable for combating malnutrition and diseases of vulnerable populations in many communities in sub-Sahara Africa. Farming households affected by HIV/AIDS have labour shortages and are using various coping strategies (Engh *et al.,* 2000; Egal and Vastar, 1999). The household health care represents 25 to 50 percent of the net annual income of most small farms in developing countries (UNAIDS, 2004). High prices of drugs and recent market orientation of health care systems limit access to medical treatment (Nnko *et al.,* 2000; Farah, 2001). Individuals infected with HIV are recommended to eat more food as their bodies require more nutrients (FAO, 2001). Low-income and HIV/AIDS-affected households often rely upon tree and forest products to complement their diets (i.e. wild food plants, bush meat, nuts, leaves and roots). Forest foods are often good sources of micronutrients (vitamins and minerals which are essential for good nutrition and health) and are essential to HIV/AIDS affected households. As Table 20.2 shows, some fruits in the forest contain high amounts of vitamins and nutrients. Wild supplies of food comprises much more of the diet of subsistence populations than is often realized (Hoskins, 1990). HIV/AIDS affected households tend to attach more importance to forest product collection than non-affected households (Barany *et al.,* 2005). Approximately 1,500 species of wild plants have been reported as being collected for consumption in central and West Africa (Chege, 1994).

There are many trees that produce oil seeds, edible leaves and fruits that are rich in important vitamins and nutritional elements (Hoskins, 1990; Ogden, 1990). After the oil palm, the shea-butter tree (*Butryospermum paradoxm*) has been reported as the second most important source of fat in African diets (FAO, 1995). In some areas, wild game from forests provides most of the protein eaten by rural populations (Bennett and Robinson, 2000). Dietary supplementation with forest and tree products can play an important role in community nutrition given growing evidence that malnutrition is a major underlying cause for the rapid expression of AIDS in Africa's HIV-infected individuals (Enwonwu and Warren, 2001). There is evidence that agricultural labour and cash shortages amongst HIV/AIDS affected households have led to the reversion and increased consumption of wild foods, including fruits, nuts, leafy vegetables, fungi and protein sources such as bush meat and insects, (Kengni *et al.,* 2004).

Table 20.2. Some Neotropical Fruits in Brazil that are Excellent Sources of Provitamin a

Fruit	**Portion analyzed**	**α-carotene *(µg/g)***	**β-carotene *(µg/g)***	**β-cryptoxanthin *(µg/g)***	**Other carotenoid *(µg/g)***	**Vitamin A activity in mixed foods *(Retinol activity equivalents/100 g)***
Mauritia vinifera	Pulp	80.5	360		γ-carotene, 37	3050
Astrocaryum vulgare	Pulp		107	3.6	b-zeacarotene, 5.9	930
Eugenia uniflora	Pulp		9.5			830
Acrocomia makayayba	Pulp		55			490
Bactris gasipaes	Boiled pulp	3.2	22		γ-carotene, 18	270
Malpighia glabra	Pulp		26	3.6		230
Mammea americana	Pulp		14		β-apo-10'-carotenal, 5 β-apo-8'-carotenol,11	195
Spondias lutea	Pulp and peel		1.4	17.0		93
Cariocar villosum	Pulp		1.2	4.4		30

Note: By comparison, mango (*Mangifera* spp.) and papaya (*Carica papaya*) provide 38–257 and 25–150 retinol activity equivalents per 100 g, respectively (USDA, 2004).

Source: Adapted from Rodriguez-Amaya, 1996

Wild plants are a principal source of traditional medicines (leaves, roots, etc.) that may help to treat many of the symptoms of opportunistic infections that are associated with AIDS. Indigenous medicinal plants (including cultivated tree nuts and wild fruits) may also boost the immune system of HIV/AIDS patients. In SSA, health care is largely a forest-based service (Chege, 1994). Forests and trees are valued by agrarian communities for their supply of medicinal products (Hoskins, 1990), and plant-based remedies are used increasingly in the region to treat HIV/AIDS-related illnesses (Bodeker *et al.,* 2000). Many households turn to traditional remedies to help ease some of the suffering of ailing household members, particularly from HIV/AIDS related opportunistic infections. These medicines may be collected by household members or purchased from traditional healers and medicinal plant vendors. Traditional remedies are often more affordable than conventional, western medicines, and consequently favoured (Kungu *et al.,* 2006).

In Tanzania, the Tanga AIDS working Group is reported to treat AIDS patients with herbs prescribed by traditional healers (Hayman, 2001). At the Mefopla Centre in Cameroon, efforts to boost the immune system of AIDS patients involve indigenous medicinal plants with enzyme-rich food, including cultivated tree nuts and wild fruits (Kinyuy, 2001). Not only do forest and tree products directly contribute to nutrition and health, but they also contribute to the accessibility of food and health care by increasing household purchasing power. The erosion of productive assets and loss of agricultural productivity resulting from HIV/AIDS, suggests that afflicted households in rural Africa increases their dependence on such natural resources as both a temporary coping strategy, and/or as a more permanent livelihood strategy (Barany *et al.,* 2001). At the household level, HIV/AIDS morbidity and mortality increase the amount of time and money allocated to healthcare while reducing labour and productivity. Household responses to these impacts include the reduction in the area of land cultivated, the reduction of farm inputs, and the sale of assets such as livestock and land (Baier, 1997; Barnett and Blaikie, 1992; Engh *et al.,* 2000; UNAIDS, 1999). Such responses ultimately lead to food insecurity and deeper poverty (Egal and Valstar, 1999; Topouzis and Hemrich, 1996). Food insecurity and poverty are both positively correlated with dependence on natural resources. Rural households often turn to natural resources in response to agricultural shortfalls and other contingencies (Campbell *et al.,* 2002; Loibooki *et al.,* 2002; Pattanayak and Sills, 2001). For example, in northwest Tanzania, Loibooki *et al.* (2002) reports that households responds to crop failure by hunting bushmeat for consumption and sale.

The growing demand for traditional medicines created by HIV/AIDS pandemic is likely to increase pressures on existing stocks possibly leading to scarcity in the future (Barany *et al.,* 2005). Barnett and Haslwimmer (1995) describe the participation of afflicted households in Uganda in reed-mat making and bark-cloth production. Menzel and DAluisio (1998) describe the reliance of a suspected AIDS orphan on the collection of woodland caterpillars in an effort to generate cash to care for her siblings. Afflicted households have been observed to substitute purchased food with wild vegetables (Mutangadura *et al.,* 1999). HIV/AIDS widows in Zimbabwe are reported to rely on production of baskets with fibres collected from local woodlands as their main source of income. Nutrition interventions are considered one of the most important components in the treatment and care for people living with HIV/AIDS (Haddad and Gillespie, 2001; USAID, 2001). However, afflicted households in sub-Saharan Africa find it difficult following nutritional guidelines which promote foods that are not available (Nnko *et al.,* 2000). The nutritional contents of various species of wild fruits, vegetables, nuts, insects and animals commonly gathered from forests in sub-Saharan Africa compare favourably to those of conventional foods recommended to improve the well-being of people living with HIV/AIDS (PLWHA) and are high in specific nutrients of particular importance to PLWHA (Barany *et al.,* Forthcoming). If HIV/AIDS increases dependence on natural resources for food, then the development of nutritional guidelines for afflicted households in sub-Saharan Africa can benefit by integrated efforts (of the health and natural resource management sectors) to identify locally available and nutritionally valuable foods.

Interventions that improve household economic access to food and healthcare are important components of HIV/AIDS programs in Africa (USAID, 2002). Interventions including the development of marketing skills, small-scale enterprises, and micro-finance schemes all require linkages to adequate markets. Markets for certain natural resource products that are affordable substitutes for manufactured goods (e.g., medicinal plants) are likely to expand in relation to the epidemic, providing commercial opportunities for those entering into natural resource-based income-generating activities (Barany *et al.,* 2003). Determining if afflicted households increase dependence on natural resources for income is the first step in linking the activities of these households to markets through market-oriented interventions. Several distinct features define natural resources as unique economic resources for rural households (Cavendish, 2000). They provide a wide array of products to meet numerous needs. Among these are wild foods for consumption, non-food direct uses such as medicine, materials for handicrafts (e.g., grasses, reeds, and canes for baskets and mats), wood for energy, construction, and agricultural implements, and other products such as fodder for livestock feed and fertilizer. In north central Tanzania, pastoralists responded to their eviction from grazing lands by entering the medicinal plant trade (Brockington, 2001). Households fall back on forest-based activities because these activities require minimal capital inputs. For the same reason, natural resource-based activities contribute more consistently to the livelihoods of the rural poor (Reddy and Chakravarty, 1999; Cavendish, 2000; Arnold, 2001; Shackleton *et al.,* 2002). Consequently, women typically make up the majority of those involved in natural resource-based activities (FAO, 1989).

HIV/AIDS treatment and medicinal plant resources

Sub-Saharan Africa has the fastest rate of deforestation in the world (FAO, 2001). Those natural resources remaining accessible to the public are vulnerable to the tragedy of the commons. Additionally, formal and informal natural resource management and conservation institutions are losing staff and finances to HIV/AIDS (Dwasi, 2002). While the role of natural resources in household responses to HIV/AIDS has yet to be explored, dependence on traditional medicine and medicinal plants is a known natural resource-based community-level response to HIV/AIDS (Good, 1989, 1996). Since the World Health Organization first advocated the inclusion of traditional health systems in the treatment and care of PLWHA in 1990, national ministries of health and non-governmental organizations (NGOs) continue to form collaborative arrangements with traditional health sectors relying on medicinal plants for the treatment of HIV/AIDS related infections and conditions such as herpes zoster, thrush, diarrhoea, and appetite loss (Bodeker *et al.,* 2000; King, 2000). Reliance on medicinal plants as a response to HIV/AIDS treatment and care is primarily a function of economic and physical accessibility. However, where demand for medicinal plants exceeds local supply, over-harvesting can lead to poorer quality and higher prices for medicinal plants, undermining this accessibility (Mander, 1998). In extreme instances, species scarcity has pushed the price of certain medicinal plants higher than their manufactured substitutes (e.g., *Walburgia salutaris*) (Cunningham, 1997). Traditional healers at the 13th International AIDS Conference in Durban, South Africa (2000) indicated that the natural stocks of medicinal plants used in their treatment of HIV/AIDS-related illnesses are declining.

Exploratory analysis of the demand for specific medicinal plant species used in treating HIV/AIDS-related illnesses in relation to the natural resources from which these plants are harvested will determine the need for, and types of natural resource management interventions to help ensure the sustainability of local responses to HIV/AIDS. For example, the domestication of wild plant species in farming systems requires substantial investment in research and development (Tchoundjeu *et al.,* 2002). Assuming domestication that maintains a species medical efficacy is possible; the high input costs associated with medicinal plant cultivation has proven uncompetitive when a supply shortfall in one geographic area is compensated by an increase of harvesting in another (Cunningham, 1997). Details regarding change in medicinal plant populations, shifts in harvesting areas, policies governing these areas, and those involved in harvesting will help inform the feasibility of alternative interventions such as better management of wild resources and the improvement of harvesting methods.

Timber and non-timber forest products and HIV and AIDS

Trees, forests and woodlands provide materials for housing, roofing, and lighting. They also provide fuel wood which is essential for cooking, as well as drying and heating. Forests and trees also provide fibre, timber, fodder and mushrooms which can reduce expenditure and generate income. Timber and non-timber products may be used as a source of livelihood through value adding (i.e. handicrafts, furniture-making, and beekeeping). Perhaps one of the most important non timber forest products to household nutrition and health is fuel wood. In some regions of Africa, fuel wood comprises between 61 and 86 percent of the primary energy consumption, with 74 to 97 percent of this consumed by households (Amous, 2000).

The availability of fuel often determines the nutritional values of meals (Egal *et al.,* 2000), as cooking releases nutrients in grains and fibrous foods. HIV/AIDS affected households often increase their consumption of fuel wood, since they can no longer afford to purchase alternatives. A study carried out in Malawi revealed that households that had experienced the loss of a working aged adult were five times more likely to have increased fuel wood collection than non-affected households (Barany *et al.,* 2005). The increased frequency of funerals also results in escalated demands for fuel wood and other traditional products associated with burials such as reed mats. In the long-term, this expanded use may have negative impact on the forest resources.

Wild supplies of food make up much more of subsistence population's dietary value than is often realized (Hoskins 1990). There are approximately 1,500 species of wild plants collected for consumption in Central and West Africa (Chege, 1994). In parts of Africa, diets based on staple grains depend largely on tree products to provide essential vitamins. For instance, many trees produce oil seeds, edible leaves, and fruits rich in important vitamins and nutritional elements (Hoskins 1990; Ogden 1990). Other nutrition values are obtained from forest and trees. After the oil palm, the shea-butter tree (*Butyrospermum paradoxm*) is the main source of fat in Africa (FAO 1995). In some areas, wild game from forests provides most of the protein eaten by rural populations (FAO 1995; Bennett and Robinson 2000). In the context of the current epidemic, dietary supplementation with forest and tree products may play an important role in community nutrition considering the growing evidence that malnutrition (specifically depleted micronutrient status) is a major underlying cause for the rapid progression to AIDS in Africa's HIV infected individuals (Enwonwu and Warren, 2001).

Perhaps one of the most important NTFPs necessary to household nutrition and health is fuel wood. In some regions of Africa, fuel wood comprises between 61 to 86% of the primary energy consumption, with 74 to 97 % of this consumed by households (Amous, 2000). The availability of fuel often determines the nutritional value of meals (Egal *et al.,* 2000). Fuel wood is essential if food supplies are to be converted into adequate diets as it provides most of the energy for cooking, which releases nutrients in grains and fibrous foods. For example, cassava (*Manihot esculenta*), a staple root crop of many people in the developing world, requires processing, often by fire, to remove toxic levels of cyanide in the pre-processed root. It is presumed that access to this NTFP can be directly related to household food cooking time, frequency of parasitic diseases, and the workload of women amongst some communities (Anonymous, 1990). In SSA, health care is largely a forest-based service (Chege, 1994). Forests and trees are valued by agrarian communities for their supply of medicinal NTFPs (Hoskins 1990). Plant-based remedies in various SSA countries are more frequently being used for the treatment of HIV/AIDS-related illnesses (Bodeker *et al.,* 2000). In Tanzania, the Tanga AIDS Working Group (TAWG) is treating AIDS patients with herbs prescribed by traditional healers (Hayman, 2001). At the Mefopla Centre in Cameroon, efforts to boost the immune system of AIDS patients involve indigenous medicinal plants with enzyme rich food including cultivated tree nuts and wild fruits (Kinyuy, 2001). Not only do forest and tree products directly contribute to nutrition and health, but they also contribute to the accessibility of food and health care by increasing household purchasing power Home-based production and trading activities, often using traditional skills such as weaving, are frequently a 'last resort' option for income for widows, grandmothers left with AIDS orphans to care for, or even for orphans themselves. Shackleton (2005) reports that in Bushbuckridge, South Africa, at least 10% of mat weavers and traditional hand broom producers were elderly women with sole responsibility for their grandchildren. They had entered the trade for much needed extra income to pay school fees and purchase food. Case studies from across South Africa indicate that a significant proportion of female crafters head their own households (between 50-70%), with many of these women having been recently widowed. Similarly, selling woven products has been found to constitute an important coping strategy following illness and death in households in Mozambique, Malawi (Barany *et al.,* 2005) and Uganda (Barnett and Haslwimmer, 1995). Non-timber forest products (NTFPs) are commonly offered for sale and provide employment. In Ghana, a study of seven villages found household incomes derived from NTFPs range between 49 and 87 percent; while in Cameroon, extractive activities around one forest contribute to over half of local incomes (Chege, 1994).

Markets for NTFPs are growing as large urban centres and scarce forest resources create demands for high value NTFPs. In West Africa, the roots of *Swartzia Madagascar* are traded distances over 500 km (Cunningham 1993). The under story plants belonging to the genus *Gnetum* are exported from Central Africa to Europe (Mialoundama, 1993). Even when the amount of income generated by the sale of fruit, fuel wood, etc, may not be that large, it can play an important role in household expenses (Scherr, 1995). Caterpillars that feed on the leaves of the Mopane tree (*Colophospermum mopane*) are a cash crop in southern Africa. One report documents the reliance of an AIDS orphan on this economic activity in an effort to care for her siblings (Menzel and DAluisio, 1998). Over-extraction of the caterpillar is threatening the sustainability of this activity so there are current efforts to establish mopane farming.

Conclusion

With most people in African countries living in the rural areas, it is unlikely that the HIV/AIDS epidemic can be controlled without the effective support of forestry sector. Creating awareness on forest biodiversity and local knowledge can be one way to mitigate the effects of HIV/AIDS. Having policies that focus on timber and non-timber products can help to promote food security and nutrition, medicinal relief, and income generation. Successful interventions to support the use of forest biodiversity for health objectives are likely to be multi-sect oral, multidisciplinary and problem focused. Diversity-based approaches to improving nutrition and health depend on the conservation and sustainable use of forest and other wild species and biodiversity.

There is need to formulate and implement effective policy strategies which recognise the involvement and participation of different stakeholders. At the national level, ministries responsible for environment, health and nutrition, agriculture, forestry, economic development, culture and education could work together to create awareness of forest products and their role in fighting and controlling HIV/AIDS epidemics. This can only happens if the relevant policies are in place.

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21. Impact of Harvesting Machinery on Soil Physical Parameters: Assessment of Profor Model's Relevance in Three Main Forestry Regions of South Africa.

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Abstract

Timber harvesting operations in plantation forestry in South Africa are rapidly being mechanised. Machine movement over forest soils increases the potential for soil compaction and hence soil damage. In order to prevent said soil damage, the Technical University of Munich developed a computer model called *ProFor*. This model enables the calculation of critical soil water content for a given machine and physical soil characteristic beyond which soil damage is likely to occur. The model is currently being used by forestry industries in some European countries. This study was conducted to assess the model's relevance in the South African forestry. The study was conducted in four harvesting sites located in three of the major forestry regions of South Africa, namely KwaZulu-Natal; Eastern Cape and the Western Cape. The impact of mechanised harvesting equipment on soil physical properties was assessed through evaluation of changes in soil bulk density. The changes in soil physical properties were then compared with *ProFor*'s predictions. The study has indicated that *ProFor* gave good predictions of the critical moisture contents for most of the studied soils except for sandy soils. However, *ProFor* predictions poorly correlated ($r^2 = -0.1$) with the observed soil compaction. The model can be adopted for the South African forestry industry for use in the management of wet spots of a plantation. However, *ProFor* can be of even greater importance if a separate algorithm was built-in to be used for the prediction of soil compaction which is a common hazard in most South African forestry.

Key words: Forest harvesting, *ProFor,* soil compaction, bulk density

Introduction

Timber harvesting operations in plantation forestry in South Africa are rapidly being mechanised. One of the contributing factors is the need to improve productivity, wood quality, and safety of operations. The prevalence of HIV/ AIDS has also led to the scarcity of manual labour in the South African forestry industry due to the depopulation of the rural areas (Clarke and Moenieba, 2004). In addition, HIV/AIDS has had an impact on the fitness of the available labour to sustain high productivity levels under the prevailing conditions of manual harvesting operations. In the light of these factors, mechanisation of timber harvesting operations acts like both a remedy and an alternative, which make it attractive to South African plantation forestry industry. However, research has shown that forest harvesting machines have the potential to cause soil disturbances such as soil compaction, rutting and erosion (Greacen and Sands, 1980;

Smith *et al.,* 1997). These disturbances could have a harmful effect on site productivity (Murphy *et al.,* 2004). Therefore, if the productivity of the major timber growing areas of South Africa is to be sustained, potential soil damage caused by forest machines must be prevented.

Machine-soil interaction is influenced by a number of factors, the most important being soil physical parameters, total mass and mass distribution of the machine, number of wheels in contact with the soil and the tyre construction elements (Hillel, 1982). The main soil parameters that affect the ability of the soil to carry a certain load without being damaged are soil water content, soil texture, humus content, skeleton content (soil particles >2mm) and slope of the terrain. Of these parameters, only soil water content changes over time. This knowledge and data could therefore enable the calculation of critical soil water content for a given soil, as well as the machine and terrain conditions for the prevention of soil damage. However, in order to precisely predict the critical soil water content, an understanding of the principles of plastic and liquid limits of soils is crucial. The plastic limit of a soil refers to the soil water content dry enough to bear mechanical loads typical for forestry machinery without risk of deformation. On the other hand, liquid limit refers to the soil moisture content at which the soil changes from plastic state to liquid state (Matthies *et al*., 2006). This then means that forest management operations in soils with a water content status closer to the plastic limit than to the liquid limit could be acceptable. Based on this premise, a model named *ProFor* was developed. The model is capable of predicting the limiting moisture content of any specific soil type (Ziesak, 2003). The limiting soil moisture content lies between the plastic and liquid limits of the soil being tested (Figure 21.1). According to Ziesak, 2003, the model can be used as a tactical and strategic planning instrument enabling forest enterprises to prevent soil critical operations.

The model essentially requires two main data input variables namely: soil and machine configuration data. For the soil data, the model requires information on soil physical parameters related to the compartment being studied. These include, sand, silt and clay percentages as obtained from the particle size analysis, the humus content (<5%, >5%), whether the soil experiences alterations in the water table, the skeleton content i.e. gravel percentage (<30%, 30-50%, >50%) and the slope (<15%, 15-30%). Machine configuration data include the name of the machine being used, type and size of tyres on both the front and the rear axles of the machine, and the inflation pressures of both rear and front axle tyres. This model is currently being used in some European countries such as Italy and France (Ziesak, 2003). However, for its application in the South African forestry industry, evaluation under South African conditions was necessary. This objective was achieved through the evaluation of the on-site impacts of harvesting equipment on soil physical properties and comparing them with *ProFor's* predicted values.

Materials and methods

Study sites

Four timber harvesting sites were selected in three of the major plantation forestry regions of South Africa including KwaZulu-Natal (Glengarry plantation), Eastern Cape (Blueliliesbush plantation), and Western Cape (Grabouw plantation- compartments B21 and M1).The selected sites differed in a range of climatic conditions, parent materials and soil types(Table 21.1).

Prior to the study, management history of the site was obtained to avoid the selection of compartments with previous machine harvesting or thinning history which could affect the soils response to machine trafficking. The terrain for the study sites was classified based on South African Forestry Classification System (Table 21.2). The specifications of the machines used in the study are presented in Table 21.3.

For each study site the empty machines were allowed to make four passes at a normal infield speed (5km per hour) and with minimal deviations from the original track. Hatchell *et al*. (1981) showed that only four passes are needed to reach 90% of the maximum density in surface soils although density continues to increase in amount and depth with the number of passes. After four passes, sampling points were selected systematically at 5-m intervals within the track and marked with paint. Adjacent to the sampling points in the track; 'control' sampling points (virgin area) were also selected and marked. On each point, three disturbed soil samples were collected at a depth of 7 cm. Soil sampling was done by using a hammer driven core cylinder device. The core cylinder was 7cm high and 7.1cm in diameter (273.4 cm^3 in volume). Soil texture was determined using the pipette method (Soil Classification Working Group, 1991).

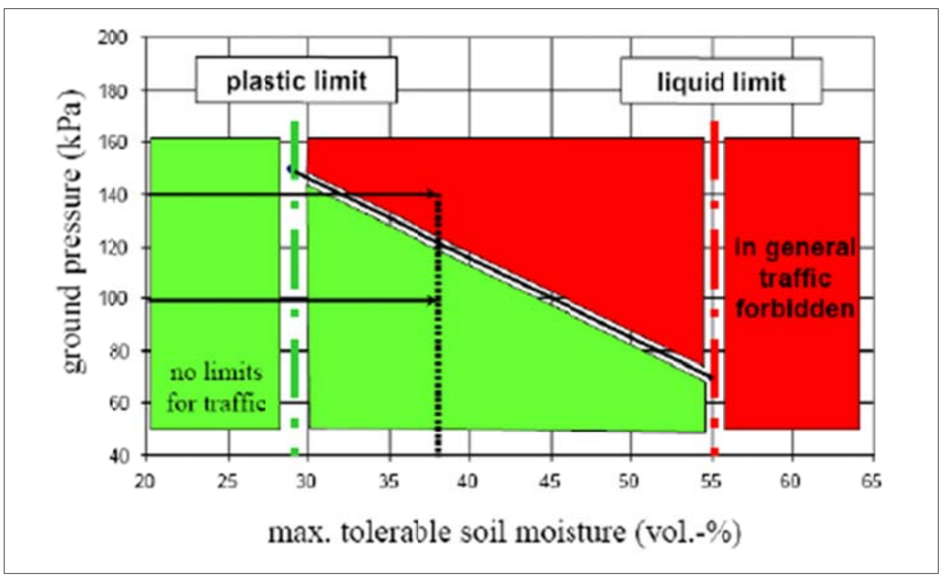

Figure 21.1. A schematic diagram of *ProFor* predictions of the critical soil moisture contents for a sandy loamy soil (Ziesak, 2003).

Table 21.1: Description of timber plantations sites

Site information	**Glengarry**	**Blueliliesbush**	**Grabouw**	
	Singisi Forest Products Limited	MTO Forestry	MTO Forestry	MTO Forestry
Compartment	A4	B28	B21	M1
Region	KwaZulu-Natal	Eastern Cape	Western Cape	Western Cape
Latitude	30^{o} 33'14.71"	24^{o}20'32.52	19^{o}01'47.20"	19^{o}06'10
Longitude	29^{o}25'36.36"S	34^{o}04'50.77"	34^{o}05'09.40	34^{o}11'56.57
Rainfall distribution	Summer rainfall	All year	Winter rainfall	Winter rainfall
Mean Annual Precipitation(mm)	800	1082	1061	1061
Species planted	*Pinus patula*	*Pinus pinaster*	*Pinus radiata*	*Pinus radiata*
Date of Experiment	9th of November, 2006	17th of February 2007	8th June 2007	20th June 2007
Mean Monthly Precipitation for November(mm)	800	79	180	180
Age	25 years	28 years	35 year	35 year

Table 21.2. Terrain Classification for forestry in South Africa

Plantation/compartment	**Terrain classification**	**Description**
Glengarry /A4	135.2.3	Ground conditions(135): Very good when dry(1), moderate when moist(3), very poor when wet(5), Ground roughness(2): Slightly uneven Slope(3): Moderate i.e. 21-25% gradient
Blueliliesbush/B28	333.1.2	Ground conditions (333): moderate when dry (3), moderate when moist (3), moderate when wet (3) i.e. behaviour not dependent on moisture content. Ground roughness(1): Smooth Slope(2): Gentle i.e. 13-20% gradient
Grabouw/B21	135.1.2	Ground conditions (135): Very good when dry (1), moderate when moist (3), very poor when wet (5). Ground roughness(1): Smooth Slope(2): Gentle i.e. 13-20% gradient
Grabouw/M1	133.2.2	Ground conditions(133): Very good when dry(1), moderate when moist(3), and wet(3), Ground roughness(1): Smooth Slope(3): Gentle i.e. 13-20 % gradient

Source: South African forestry handbook, 2000

Table 21.3: Specifications for machines used in the study and rear axle tyre pressure.

	Area/ machine			
	Glengarry plantation Timberjack 460D Cable Skidder	**Blueliliesbush** plantation John Deere 648G-111 TC Grapple Skidder	**Grabouw** Plantation (B21) Timberjack 380C Cable Skidder	**Grabouw** Plantation(M1) Clark Ranger F66 Cable Skidder
Operating tare mass	11282 kg	13934 kg	10355 kg	7893 kg
Tyre name	General	Logger	General	General
Tyre manufacture	Bridgestone	Firestone	Bridgestone	Bridgestone
Tyre configurations	28L - 26	30.5 – 32	23.1 – 26	23.1 - 26
Tyre ply rating	12	16	16	16
Tyre width(mm)	711	774	587	587
Tyre pressure(bars)	(2.0a, 1.5b)	(1.8a, 1.75b)	(2.65a, 2.3b)	(2.0a, 1.95b)

a and b refer to front and rear axle pressure

The evaluation indicate that there were significant ($p<0.05$) differences between *ProFor* predictions and bulk density with F value of 4.1 ($P = 0.04$) suggesting poor correlation ($r = -0.1$) of *ProFor* predictions with changes in soil bulk density. This implies that *ProFor* predicts poorly on soil compaction i.e. increases in soil bulk density.

The soil texture was described in terms of the percentages of clay (□0.002mm), fine silt (0.002-0.02mm), course silt (0.02-0.05mm), fine sand (0.05-0.25mm), medium sand (0.25-0.50mm) and course sand (0.5 - 2.00mm).

Volumetric soil water content was determined using the gravimetric soil sampling method. The soil samples were weighed on the same day they were collected to obtain initial masses. The samples were then dried in an oven (105^0C) for a period of 24 hours. The amount of water in the soil was determined by subtracting the oven-dry mass from the initial field soil mass. The mass of the water was then divided by the volume of soil. (Equation 1):

$$W \text{ (volume-\%)} = ((W_w - W_d)/ \text{mass of soil}) * \text{bulk density } (g/cm^3) \qquad \text{(equation 1)}$$

Where: W= Volumetric water content (%);
W_w = mass of wet soil (g) and
W_d= oven dried soil mass (g)

Soil bulk density which expresses the ratio of the mass of dried soil to its total volume was determined using the following formula.

$$\rho_d = M_1/V_1 \qquad \text{(Equation 2)}$$

Where: ρ_d = Dry soil bulk density (g cm^{-3});
M1 = Mass of oven dried soil (g) and

V1 = Volume of soil (cm^3)

The plastic limits of the soils were determined using the 3mm thread rolling method (Head, 1980), while the liquid limits were determined using the Casagrande apparatus (Head, 1980). In both cases, the dry method procedure for preparing the samples was used.

Data analysis

The data was analysed using repeated measures analysis of variance (RMANOVA) and nonparametric tests thus using. Wilcoxn matched pairs test. All the data was analysed at 95% level of significance.

Results

Soil physical parameters

Soils textures, plastic limits and liquid limits of the soils for the three plantations are presented in (Table 21.4)

Table 21.4: Soil classes, textures and Atterberg limits of the soils for Glengarry, Blueliliesbush and Grabouw plantations.

	Soil texture							**Atterberg limits (%)**	
	Clay	**Sand**	**Silt**	**Class**		**θ**	**θ**	**Plastic**	**Liquid**
	30	23	47	Clay loam	6	28	25	21	35
	23	37	40	Clay loam	3	27	27	26	35
	42	23	35	Clay loam	5	29	28	27	41
	22	60	18	Sandy clay loam	14	47	25	26	38
	17	49	34	Loam	0	14	24	21	23
	12	49	39	Sandy loam	0	10	24	16	21
	13	65	22	Sandy loam	0	12	16	16	20
	14	58	28	Sandy loam	0	12	16	21	21
Grabouw B21	20	62	18	Sandy clay loam	0	30	30	21	31
	29	42	29	Clay loam	5	39	30	34	46
	33	31	36	Clay loam	6	33	30	35	51
	34	36	30	Clay loam	7	40	30	30	46
	37	35	28	Clay loam	4	48		35	46
Grabouw M1	28	35	37	Clay loam	14	28	30	26	32
	23	36	41	Loam	13	30	24	27	33
	23	39	38	Loam	18	26	24	25	29
	25	43	33	Loam	15	29	30	25	30
	25	38	37	Loam	20	42	30	26	34

Soil bulk density

Significant increases (p <0.005) in soil bulk density were observed both at the Blueliliesbush and Grabouw (compartments B21and M1) plantations. However, a decrease in soil bulk density was observed in Glengarry plantation (Figure 21.2).

ProFor prediction of critical soil moisture content

ProFor predicted critical soil moisture content, plastic limits and liquid limits is presented in Table 21.5. The results indicate that in the Glengarry and the Grabouw (B21) sites the initial moisture contents (θv) were above the predicted value of the critical moisture content. On the other hand all the critical soil moisture contents as predicted by *ProFor* lie between the plastic and liquid limits in all the four sites which is an indication that the models predictions were within the acceptable limits based on the premise as described in the introduction section.

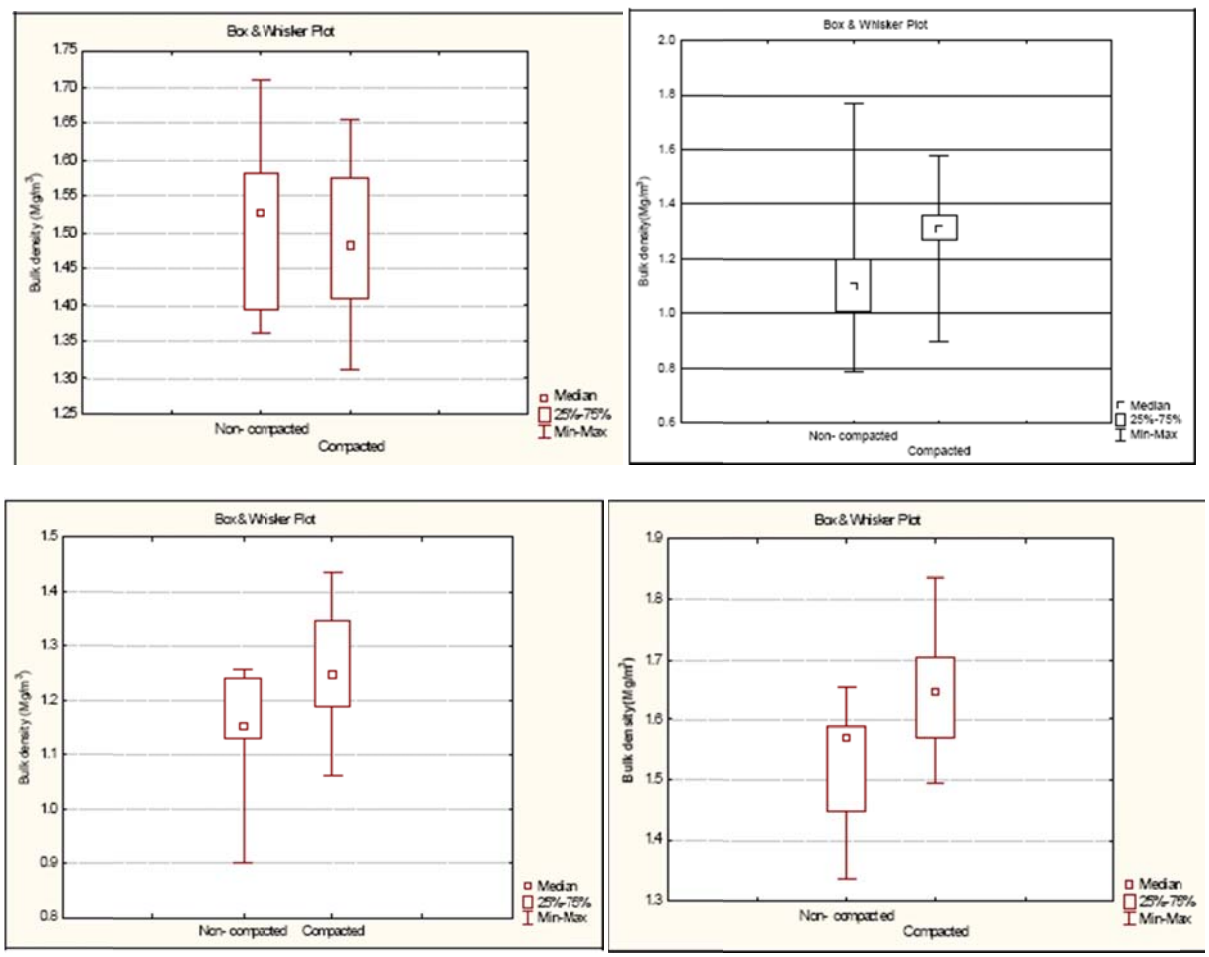

Figure 21.2: Box plots of changes in bulk density in Glengarry (a), Blueliliesbush, Grabouw compartment B21(c) and Grabouw compartment M1(c) plantations.

Discussion

The soil bulk density increased significantly at Blueliliesbush and Grabouw plantations and this could be attributed to differences in soil texture than soil moisture content at the time of experimentation because the initial soil moisture contents for all the points on this site were below the plastic limit. (Figure 21.3). The dominant soil texture for the compartment was sandy loam. Smith *et al.,* (1997a) that sandy loam textured soils are almost independent of soil moisture content when they are being compacted and increases in soil bulk density is almost entirely attributed to the increase in ground pressure. This is also supported by the findings of Smith *et al*. (1997) who have observed that sandy loam soils achieve higher bulk densities when it is very dry. This is the case because dry sands are always packed more closely under a given load due to the loss of annular bridges which are formed between sand particles when the soil is moist but are lost when the soil is dry. The significant increases in soil bulk densities observed in the two Grabouw plantations' study sites could however be attributed to both the soil texture and the soil moisture content at the time of experimentation because dominant soil texture for both compartments was clay loam. Hillel (1982) indicated that for clayey soils bulk density increases with an increase in soil moisture content until the optimum moisture content is achieved. In this study both compartments, the initial volumetric soil moisture content were between plastic and liquid limit supporting Hillel's results (Table 21.4). On the other hand, a decrease in soil bulk density was observed in the Glengarry plantation mainly be due to the soil disturbances caused by machine movement due to the presence of thick undergrowth and deadwood lying on the forest floor compared to the other three sites. The undergrowth and deadwood were not removed prior to the experiment to avoid disturbing the soil.

Table 21.5: *ProFor* prediction for critical soil moisture content

			θθ	**Atterberg limits (%)**	
	θ	**θ**		**Plastic**	**Liquid**
	28	25	3	21	35
	27	27	0	26	35
	29	28	1	27	41
	47	25	22	26	38
	14	24	-10	21	23
	10	24	-14	16	21
	12	16	-4	16	20
	12	16	-4	21	21
Grabouw B21	30	30	0	21	31
	39	30	9	34	46
	33	30	3	35	51
	40	30	10	30	46
	48	30	18	35	46
Grabouw M1	28	30	-2	26	32
	30	24	6	27	33
	26	24	2	25	29
	29	30	-1	25	30
	42	30	12	26	34

Assessment of *ProFor* predictions on soil bulk density

Changes in soil bulk density were used as an indicator of soil damage in this study. In order to assess the quality of *ProFor* predictions on changes in soil bulk density, *ProFor* predictions on soil damage were evaluated based on the criteria presented in the Table 21.6.

Table 21.6: Quality of ProFor predictions on soil compaction

Parameter	Description	Category
	$(\theta_v - \theta^c_v) > 0$	Damage
	$(\theta_v - \theta^c_v) < 0$	No damage
	$\Delta BD > 0$	Damage
	$\Delta BD < 0$	No damage

Assessment of *ProFor* predictions on Atterberg limits

Results presented in Figure 21.3 shows that the ProFor predictions of the critical soil moisture content lay between the plastic and liquid limits but close to the plastic limits. This then means that the models predictions are within the acceptable ranges based on the premise as discussed in the introduction section of this paper that mechanised forest management operations in soils with water content status closer to the plastic limit than to the liquid limit could be acceptable. However, the model is predicting well only for soil with clay contents over 20 %. For example, Figure 21.4 indicates that for soils with clay content lower than 15 % the predicted critical water content values are well above both the liquid and plastic limits i.e. the model over-estimates the critical soils' water content for such soils.

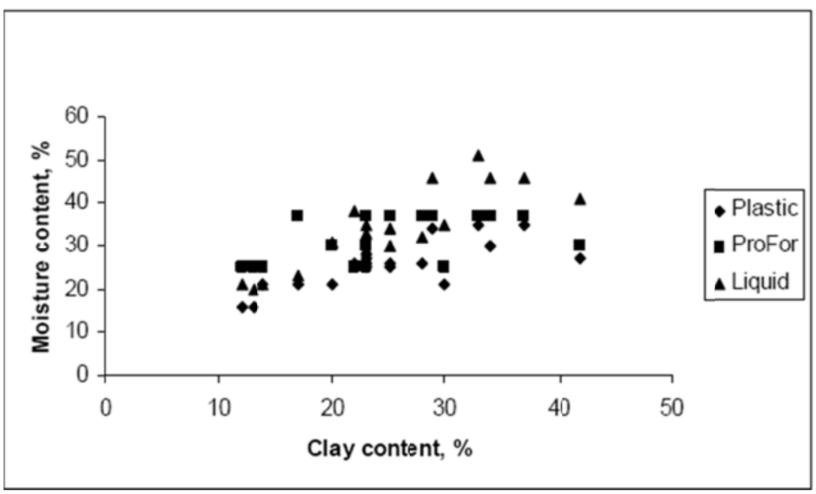

Figure 21.4: Relationship between soil clay content, plastic limit, liquid limits and the predicted critical soil water content

Conclusion

The study has indicated that soil compaction caused by four empty machine passes only resulted in significant changes in soil bulk density in three of the four study sites. These findings highlight the danger that that repeated movements of forest harvesting machines poses to the sustainability of mechanised forest harvesting operations. In an attempt to assess the accuracy of *ProFor* predictions on soil compaction, and critical soil moisture contents, comparison made between *ProFor* predictions on soil compaction indicated that *ProFor* does not provide good predictions. However, the results indicated that the model produced good predictions on critical soil moisture content. These findings show that *ProFor* could be effectively used to evaluate the accessibility of compartment during wet season. However, in the South African context, most forest regions lie in summer rainfall regions which receive rains for four to five months of the year while as the other areas are dry the rest of the year; hence soil compaction is more of a prominent problem. Therefore, the model could be complete in its predictions of possible damage if it could also be able to predict soil compactions. This could be achieved through the addition of another algorithm in the model aimed at the prediction of soil compaction. In addition, the study has also revealed that *ProFor* prediction of critical soil moisture contents on sandy soils are not good hence there is need to improve the precision of the model on sandy soils could be vital because sandy soils are liable to compact to high bulk densities as compared to the fine textured soils.

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22. Effect of Feeding Heat Treated *Moringa Oleifera* (Lam) Leaf Meal on the Growth Performance Of *Oreochromis Niloticus* (Lam) Fry.

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Abstract

The high cost and as well as the uncertain availability of fish meal have led to the need to identify alternative protein sources for feeding *Oreochromis niloticus* fry. *Moringa oleifera* is a promising protein source for inclusion in fish diets. The study was conducted to determine the suitability of heat-treated *M. oleifera* leaves as an alternative protein source for *O. niloticus* fry. Four experimental diets were formulated to contain heat-treated moringa leaf meal at levels of 5 % and 10 % of the total dietary protein. Diet A contained 5 % boiled moringa and 95 % frymeal; Diet B 10 % boiled moringa and 90 % fry meal; Diet C 5 % steamed moringa and 95 % frymeal and Diet D 10 % steamed moringa and 90 % frymeal. Diet E was the control diet containing fishmeal as the protein source. A standard 24-day fry feeding trial was carried out in 10 fry tanks that were randomly allocated to the five dietary treatments. Each tank was stocked with 15 000 fry the standard stocking rate at Lake Harvest. The growth rate, feed conversion ratio and protein efficiency ratio of fry fed the five diets were similar. The daily body weight gain ranged from 0.012 to 0.014 grams for fry fed boiled moringa and the control diets. Fry fed diets C, D and E had higher feed conversion ratio (FCR) values of 1.1, 1.1 and 1.0, respectively, compared to those on diets A and B, which had values of 1.2 and 1.3, respectively. In general, fry fed steamed moringa diets had better growth performance than those on boiled moringa diets although the differences were not significant. The results suggest that steam-heated moringa leaf meal can be used to substitute 10 % of dietary protein in Nile tilapia fry without significant reduction in growth performance.

Key words: *Moringa* feed conversion ratio, heat treatment, fishmeal replacement, growth performance.

Introduction

The Nile tilapia (*Oreochromis niloticus* Lam) was one of the first fish species cultured and is still the most widely cultured species of tilapia in Africa. Positive aquacultural characteristics of tilapia species include their tolerance to poor water quality and the fact that they eat a wide range of natural food. Of the total world production of fish, which amounted to 112.30 million tonnes in 1995, 18.97 % came from the aquaculture sector while the rest came from the captured fishery (FAO, 1998). Most of the increase in fish production is expected to come from aquaculture, which is currently the fastest growing food production sector of the world (FAO, 2000).

In aquaculture systems the increasing price of feed is considered one of the most important factors that limit profitability, caused mainly by the cost of fishmeal used as a primary source of protein (Usmani *et al*., 1997; McCoy, 1998). As a result, there is a need to search for alternative protein sources for aquaculture diets. Olvera *et al*. (1990) noted that, high cost and fluctuating quality of imported fish meal have led to the need to identify alternative protein sources for use in fish feed formulations. The identification and utilization of non-conventional and lesser–utilized plant protein sources to replace fishmeal, either partially or totally in practical fry diets has been an area of focus in aquaculture nutrition (Hossain *et al*., 2003). Earlier studies have shown that, *Moringa oleifera* (Lam) is a promising protein source for inclusion in fish diets at low levels (Becker *et al*., 2002, Chiseva, 2006). Plant proteins are cheap and readily available, but have some anti-nutritional factors that limit their use as aquaculture feeds. These limitations could be successfully overcome by different methods of heat treatment (Olvera *et al*., 1990; Afuang *et al*., 2003). The objective of the study was to determine the effects of heat-treated moringa supplemented diets on the growth performance of the Nile tilapia (*O. niloticus*) fry.

Materials and Methods

Experimental Animals

Oreochromis niloticus fry with average body weight (ABW) of 0.01 g were taken from Lake Harvest hatchery and used in this study. The collection and transportation of the fry was done as recommended by Mgaya and Tamatamah (1996) and Collart (1997). They were taken to the experimental tanks in the early hours of the day from 0500 to 0700 hr.

Fry tanks and fry stocking

The experimental tanks were thoroughly cleaned with clean fresh water before the experimental fry were introduced. A total of ten fry tanks were used and each treatment diet was randomly allocated to two fry tanks. Water in the fry tanks was continuously exchanged throughout the experiment that lasted for 24 days. A compressor was used to supply oxygen into fry tanks via air stones and this ensured adequate dissolved oxygen to be above 80 % saturation. Each individual experimental tank with the volume of 3.16 m^3 was stocked with 15 000 fry.

Fry Management

The fish fry were acclimatized in the experimental tanks for 3 days while feeding on a standard diet of 40 % crude protein. The fry were starved for a day before experimental feeding started. The fry were weighed at the beginning and progressively at weekly intervals. No feed was given on the weighing days to prevent stress.

Processing of moringa leaves and diet preparation

Moringa oleifera leaves were taken from Lake Harvest forestry unit and were dried under shed. After drying, some of the leaves were either heat treated by boiling or steam heating at a temperature of between 60 ˚C – 80 ˚C for 15 minutes. Steam heating and boiling was meant to minimize or deactivate the anti-nutritive factors such as tannins, phytic acid and saponins that inhibit the digestion of plant proteins in Nile Tilapia. After the heat treatments the leaves were allowed to dry under shed before being milled through a 0.01 mm screen. Following milling the moringa leaf meal was incorporated into the fry feed.

Four isonitrogenous diets were formulated to have 450 g/kg DM of crude protein (CP). Diets A and C were composed of 5 % boiled and 5 % steamed moringa leaves, respectively, whilst 95 %

by mass was fry meal. Diets B and D were composed of 10 % boiled and 10 % steamed moringa leaf meals, respectively, whilst 90 % by mass was the fry meal. The standard fry meal, Diet E, which contained no moringa leaf meal, served as a control and had fishmeal as a protein source. Table 22.1 indicates both dietary and chemical nutrient composition of the treatments under the study.

Feeding

The fry were fed a daily ration at a rate of 15 % of bodyweight. The daily ration was divided into eight feedings per day at an hourly interval from 0800 hours to 1500 hours. The quantity of food was adjusted weekly after weighing of fry. Mortality was recorded daily and so the quantity of feed was adjusted according to the total fry weight in the tank.

Data collection

The fry in each tank were weighed weekly in order to assess their growth performance. A Tefal electronic digital scale was used to measure weights of fry per week. The fish fry were weighed and returned into their respective fry tanks. No feed was offered during sampling days. Salt was added to fry tanks at a rate of 5 mg/l after sampling to prevent stress, which would have caused high mortalities.

Growth performance were analyzed in terms of total body weight gain (BWG), average daily gain (ADG), feed offered (FO), feed conversion ratio (FCR), protein efficiency ratio (PER) and survival percentages. The following formulae as described by Siddhuraju and Becker (2003) were used:

BWG (g) = Final body weight – Initial body weight
ADG (g/d) = BWG/21 days
FO = Total dry feed offered (g)
FCR = Total dry feed offered (g)/ Live body weight gain (g)
PER = Wet body weight gain (g)/Crude protein fed (g)

Laboratory analysis

The diets were used were analyzed for dry matter (DM), crude protein (CP), crude fibre (CF), Ash, Ca, P and energy content using the standard procedures of the AOAC (1990).

Statistical Analysis

The growth performance was analysed using the one-way analysis of variance (ANOVA) using Minitab Version 12.1.

Results

Chemical composition of diets

The chemical composition of the diets is presented in Table 22.1. The diets had CP content of that ranged from 46.4 to 46.9 % CP. The crude fibre of the diets that contained moringa leaves was high, ranging from 2.95 to 4.17 % as compared to that of fry meal of 1.97 %. The ash content of diet A and C was higher as compared with other diets as shown in Table 22.1. The calcium and phosphorus concentration in the diets was not different. The energy content of the five diets ranged from 8.2 to 12.5MJ/kg.

Feed intake, growth performance and feed utilization

The growth performance and feed utilization in terms of body weight gain (BWG), average daily gain (ADG), feed conversion ratio (FCR) and protein efficiency ratio (PER) are presented in Table 22.2. There was no rejection of feed until the end of the experiment and the acceptability of the diets was similar. No mortality or any signs of disease were observed in any of the dietary groups during the study period.

There was no significant difference ($P > 0.05$) on total body weight gain and average daily gain of the fry fed the five diets. Fry on diets C, D and E produced the best FCR and PER as compared to all other diets, but this did not differ significantly ($P > 0.05$). In general, among the five diets, fry fed diets containing steamed moringa leaves showed better growth performance in terms of final body weight, gain in body weight, FCR and PER than those fed boiled moringa leaves.

Table 22.1. Dietary composition

COMPONENTS	[1]DIET A	DIET B	DIET C	DIET D	DIET E
Dry matter	87.9	89.9	88.1	89.6	90.00
Crude protein	46.5	46.4	46.7	46.4	46.9
Crude fibre	3.44	4.17	2.95	3.32	1.97
Ash content	17.27	13.37	18.57	11.03	11.12
Calcium	2.42	2.68	2.48	2.49	2.41
Phosphorus	1.42	1.5	1.76	1.14	1.07
M.E (MJ/Kg)	10.7	9.8	8.2	12.3	12.5

[1]Diet A contains 5% boiled moringa leaves and 95% fry meal
Diet B contains 10% boiled moringa leaves and 90% fry meal
Diet C contains 5% steamed moringa leaves and 95% fry meal
Diet D contains 10% steamed moringa leaves and 90% fry meal
Diet E contains fry meal only

Table 22.2: Growth performance and nutrient utilization of tilapia fed different experimental diets

PARAMETERS	DIET A	DIET B	DIET C	DIET D	DIET E
[1]IBW (g)	0.01	0.01	0.01	0.01	0.01
FBW (g)	0.261	0.253	0.279	0.288	0.298
BWG (g)	0.251	0.243	0.269	0.278	0.288
ADG (g/d)	0.012	0.012	0.013	0.013	0.014
FO (g)	3074	3074	3074	3074	3074
FCR	1.2	1.3	1.1	1.1	1.0
PER	1.8	1.7	1.9	2.0	2.0

[1]IBW = initial body weight, FBW = final body weight, BWG = body weight gain, ADG = Average daily gain, FO = Feed offered, FCR = Feed conversion ratio, PER = Protein efficiency ratio

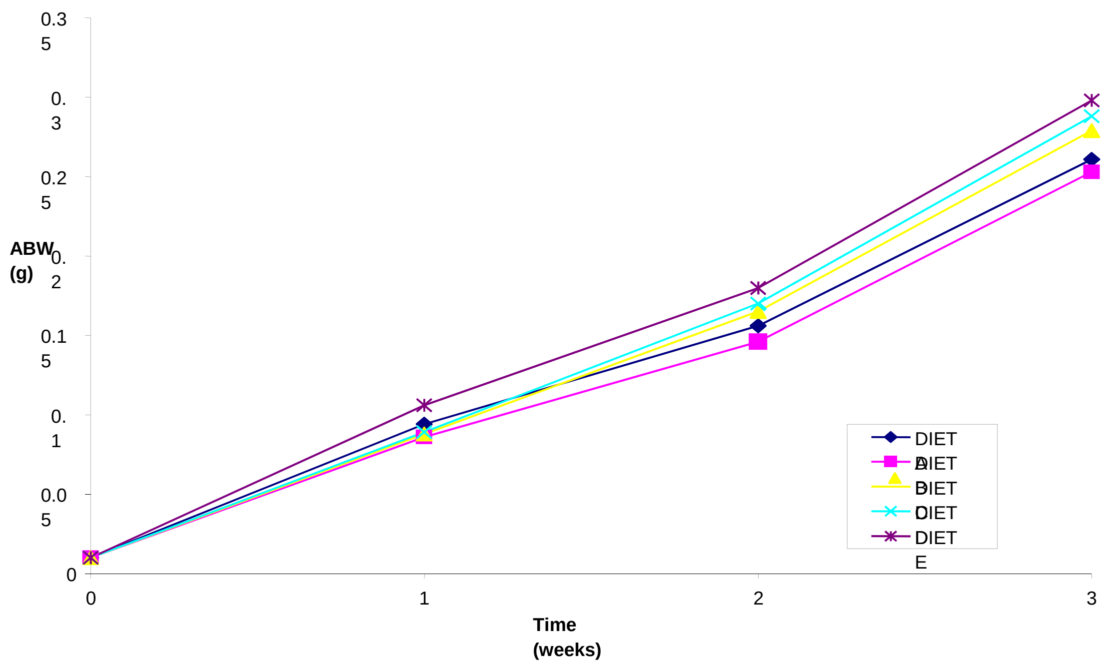

Figure 22.1. Growth curves of fish fed the five experimental diets.

The growth curves of fish fed the five experimental diets are shown in Figure 22.1. The growth of the fry showed a similar trend on all the diets during the 21-day fry stage. There was an increase in average body weight among the fry with those fed the control diet having a higher weight followed by fry fed steamed moringa leaves and lastly those fed boiled moringa leaves. Fry fed a diet with 10 % steamed moringa leaves tended to have a higher average body weight than those fed with 5 % steamed moringa leaves. On the other hand, fry fed a diet with 5 % boiled moringa leaves had a better average body weight than those on 10 % boiled moringa leaves.

Discussion

The crude protein content of the experimental diets used in this study was within the range used in a previous study by Usmani *et al*. (1997). Protein is very important in fish growth and thus crucial ingredient in fish diets. A comparison between the amino acid composition of the raw and extracted moringa leaves to that of soybean revealed an almost identical composition of essential amino acids. The proximate analysis of the experimental diets showed that the crude protein was ranging from 45.4 % to 46.9 %. This range is within Lake Harvest requirements for the growth of fry which ranges from 45 % to 47 % CP.

The diet which contained 10% steamed moringa leaves (Diet D) showed the highest growth performance as compared to all other formulated diets, except for the fry meal (Control diet) although the differences were not statistically different. In terms of growth rate, fish which received the diet which contained 5 % steamed moringa (Diet C) had low growth rate as compared to diet D. This is contrary to the previous study carried out by Richter *et al*. (2003) which showed that higher inclusion levels of moringa leaves in fish meal had an impact on lowering the growth performance because of the presence of anti-nutrients such as phenols, tannins, phytates and saponins. This present study indicate that a 10 % inclusion level of moringa in fry meal yielded good growth performance possibly because the anti-nutritrients such as phenols, tannins, phytates and saponins were could have been inactivated by steam heating as suggested by Rweyemamu (2005). This could have resulted in the reduction of palatability-reducing factors.

Heat treatment methods employed might have increased the digestibility of proteins and other dietary components such as starch related compounds leading to high FCR and PER in fish fed with diets C and D. Afuang *et al*. (2003) reported that the reduction in anti-nutrients by processing techniques such as soaking, drying and heat treatment on plant-based fish ingredients have resulted in better palatability, increased feed digestibility and growth in fish. Generally steam heating reduces loss of soluble nutrients from moringa leaves since that process does not involve a solvent media to dissolve the nutrients. Apart from that, steaming employed in this study might have resulted in little protein being denaturated thus making more quality protein been made available in steamed leaves than boiled leaves.

Boiling breaks cell components like cell walls and cell membranes of plants cells. Some of the nutrients within the cells of boiled moringa leaves were lost to boiling water during the heat treatment process. The soluble cell components such as soluble proteins and glucose molecules might have dissolved in water during boiling. This could have caused the reduction of essential amino acids (EAA) in diet A and diet B. Boiling might have caused the inactivation of anti-nutrients such as saponins, phytates, phenols and tannins that bind some quality proteins and inhibit digestion in fish. Apart from breaking the cell components; boiling induces the precipitation of polyphenolic and other phytochemical compounds which might have depressed the growth of fish receiving feed with boiled moringa leaves (Rweyemamu, 2005). Boiling also induces the formation of colloidal starches as a result this reduces the amount of available glycoproteins to fish (Rweyemamu, 2005).

Boiling and steaming showed no significant effect on the crude fibre content but it was within Lake Harvest requirements for the growth of fish; except for diet B that had a higher crude fibre content of 4.17 %. This might have contributed to the lowest growth rate of fish fed with diet B.

It has been shown that fibre can bind nutrients like fats, proteins and essential minerals, and reduce their bioavailability (Richter *et al*., 2003). Dietary fibres apparently influence the movement of nutrients along the gastrointestinal tract and significantly affect nutrient absorption.

Conclusion

The results of this study indicate that up to 10 % inclusion of steam heated moringa leaves can be recommended for *Nile tilapia*. In view of the favorable amino acid profile of moringa leaves and their wide and ready availability throughout the tropics and subtropics, moringa can be considered as a potential feed component with high nutritive value for *Nile tilapia*.

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Subtheme 3:
Global Shift Towards Bioenergy

23. Potential of Bioenergy (Biofuels) Production in Southern Africa

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Abstract
Biofuels as renewable bioenergy source came to the forefront in recent years with the threat of climate change, soaring crude oil prices and global energy security risks associated with limited oil resources. With the sub-Saharan Africa population of about 800 million bound to double by 2020, living in poverty cannot be effectively addressed without major improvements in the quality and magnitude of energy services in Africa. It has been projected that Africa could provide a quarter of the projected total world bioenergy potential by 2050 if properly managed. Biofuels hold much promise as renewable fuel of the immediate future since it can already be introduced in existing vehicle fleets. However, not all biofuel production practices are beneficial towards combating climate change and careful consideration should be given to sustainability and the carbon footprint during the production of biofuels. This paper will discuss the advent of new second generation technologies for the production of cellulosic biofuels and how this provides a larger choice of technologies and energy crops for the production of biofuels. Using South Africa as example, the potential replacement of current fossil fuel usage with second generation biofuels will be discussed. This would require (i) advanced technologies for woody plant biomass conversion to biofuels are developed, (ii) agronomists and environmentalists working together to explore sustainable bio-energy crops, and (iii) we have to adapt a more energy-conservative life style. If managed well, biofuels could make a considerable contribution to bring about foreign exchange savings on the import of crude oil, boosting local agriculture production and additional markets and revenue for farmers, generate employment and local economic development opportunities in rural areas and at the same time, assist in reducing green house gas emissions and preservation of the quality of the atmosphere.

Key words: Biofuels, renewable energy, carbon footprint, cellulosic biofuels

Why Considering Biofuels?
Biofuels, in particular biodiesel and bioethanol, recently gained much attention with soaring crude oil prices, but has to date hardly made a dent in the total volumes of petroleum fuels used worldwide. However, this is bound to change in the near future with the oil price remaining above $100/barrel, the onset of climate changes due to human activities and global energy security risks associated with limiting oil resources. Although a variety of renewable energy sources can be considered as transport fuel, bioethanol and biodiesel are seen as short-term alternatives to fossil fuels, considering the relative ease of introducing fuel blends for use in existing vehicle fleets. What makes these biofuels so attractive is that established technologies already exist for their production form renewable crops, for example starches and sugars for

bioethanol production, or vegetable oils for the production of biodiesel. Since these crops can be grown on an annual basis, CO_2 released from the production / utilization of these biofuels can in principle be recapture during photosynthesis, yielding a closed carbon neutral cycle (see Figure 23.1).

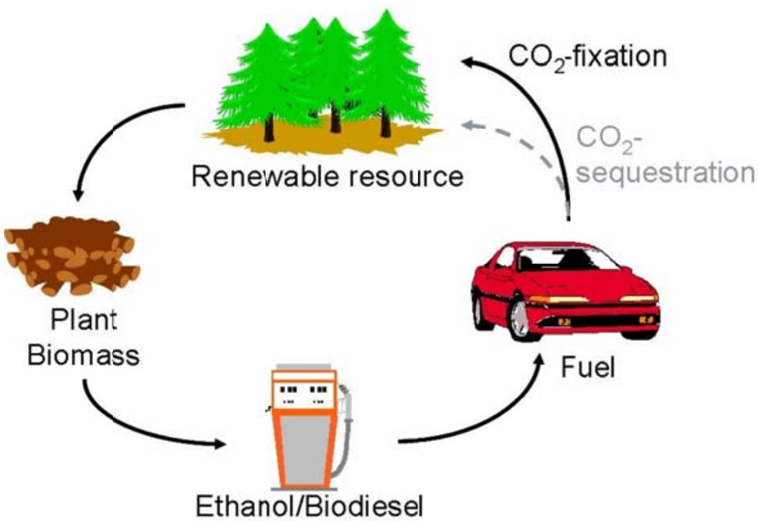

Figure 23.1: Production of biofuels from renewable biomass allows re-using and sequestration of CO_2 emissions, lowering the CO_2 footprint.

However, the use of biofuels is often not carbon neutral because fossil fuels are used during the planting and harvesting of these crops, or natural vegetation is cleared to plant the biofuel crops, which are detrimental to natural CO_2 fixation and biodiversity. On the flip-side, if agricultural practices are done in such a way that the carbon footprint is minimized and natural forests and vegetation are allowed to re-established, biofuel production can even assist in CO_2 sequestration. This is possible because a considerable portion of the carbohydrates formed produced through photosynthesis are transported through the roots to the soil microflora, whilst only the biomass above ground is used for biofuel production. It is thus crucial to understand that not all biofuel production practices are beneficial towards combating climate change, but that careful consideration should be given to the carbon footprint during the production of biofuels. This paper will discuss the advent of new second generation technologies for the production of cellulosic biofuels and how this provides a larger choice of technologies and substrates (crops or natural vegetation) for the production of biofuels.

Value of Biofuels to Sub-Saharan Africa

Energy plays a key role in the development of nations and provides vital services and means that improve quality of life. Energy is the so-call engine of economic progress. With the sub-Saharan Africa population of about 800 million bound to reach more than1.2 billion by 2020, living in poverty cannot be effectively addressed without major improvements in the quality and magnitude of energy services in Africa. In contrast to the rest of the world, poverty in Africa is primarily a rural problem. However, traditions and values have been village-driven and need to be restored for Africa to regain self-worth and self-respect. Renewable bioenergy, particularly biofuels, has played a pivotal role in Africa in the past and could help address the need for energy expansion in the future. Capitalizing on Sub-Saharan Africa's biomass potential, bringing back the focus on agriculture, re-establishing rural pride, and at the same time address social and security issues, merits a fresh look at the bioenergy potential of Africa!

A study by Smeets *et al*. (2007) projected that, depending on the level of advancement of agricultural technology, Africa has the largest potential for bioenergy production by 2050 in the world, which is 317 EJ per annum. This could constitute a quarter of the projected total world potential of 1272 EJ per annum. It should be noted that Africans traditionally have been farmers living in harmony with nature. About half of the energy used in Africa originated from biomass or agricultural residues (Amigun *et. al*., 2006). However, for Africa to realize its potential for bioenergy production as predicted by Smeets *et al*. (2007), advanced agricultural technologies and practises must be employed that would involve (i) animal production primarily taking place in feedlots, (ii) very high animal feed conversion efficiencies been achieved, (iii) super-high technology for crop production used and (iv) both rainfall and irrigation water used. Although this currently may seem impossible, a focused effort to improve agricultural practices in Africa may realize this high bioenergy potential in the next forty years.

Biofuel production could benefit Africa in several ways: it would lead to the reduction of greenhouse-gas (GHG) emissions and help combating climate change, and also serve as a source of foreign exchange savings for oil-deprived countries currently suffering due to the rising oil price. Biofuels would boost local agriculture production by providing additional markets and revenue for farmers. It would consequently generate employment and local economic development opportunities in rural areas. Last but not least, it would contribute to political security, making Africa less dependent on fossil oil and create local wealth and economic independence.

Can we Afford Food and Biofuels Production with Limited Land?

In recent months, biofuel production using first generation technologies relies on the usage of food crops and plant oils that require extensive agricultural areas traditionally used for food production, was met with fierce criticism and public debate. One approach could be to challenge the impact of biofuels on food availability and prices, considering that biofuels use less that 5% of food crops, compared to more than 95% for human and animal consumption with the bulk used as animal feeds (Dale, 2008). However, it became clear that not all biofuel production practices are necessary beneficial. In future, more careful consideration should be given to the direct impact on food production in terms of arable land available and resulting food prices, the fossil fuel required for the cultivation of biofuel crops, deforestation and unintended threatening of biodiversity by replacing natural vegetation with biofuel crops.

In December 2007, the South African government announced the long awaited 5-year national Industrial Biofuels Strategy. The mandate was for a strategy to create jobs in the energy-crop and biofuels value chain, and to act as a bridge between the first and second economy. The target for 2008-2013 is a 2 % penetration level of biofuels in the national liquid fuel supply, thus the production of 400 million litres of biofuels per annum (equivalent to one average 100 million-gallon maize-to-ethanol plant in USA). The proposed crops are sugar cane and sugar beet for bioethanol, and sunflower, canola and soya beans for biodiesel. This will require about a tenth of the 14 % arable land under-utilized (mainly in the former homelands) and has been earmarked for biofuel production. Maize is excluded due to food security concerns, as well as *Jatropha curcas* as it is considered an invasive species and more research is required to prove its suitability as biofuel crop. Tax incentives are also included, however, no mandatory blending are required. Many businesses and entrepreneurs question whether the Strategy will encourage a biofuels industry in South Africa, but the Strategy at least provide a point of departure.

The more important questions to address are whether biofuels can be an alternative to fossil fuels and if biofuels can be produced without threatening food security? The authors are of the opinion that the answers on both these questions are conditionally "Yes", providing (i) advanced technologies are developed for the conversion of more abundant woody plant biomass (called lignocellulosics) to cellulosic biofuels; (ii) agronomists and environmentalists (and plant biotechnologists?) work together to develop and manage sustainable bio-energy crops, and last but not least; and (iii) we learn to adapt a more energy-conservative life style. For the purpose of this discussion, the focus is primarily on the technological challenges, because the latter requires behavioural changes all world societies have to deal with, including those residing in Africa.

Biofuels production capacity of South Africa

South Africa has much more to offer when considering the capacity to grow total plant biomass (all lignocellulosic plant biomass) and not only the production of crops suggested by the Biofuels Industrial Strategy. A study by Lynd *et al*. (2003) found that South Africa produces about 18 million tonnes (Mt) of agricultural and forestry residues, to which can be added more than 8 Mt invasive species that would be available on an annual basis for more than a decade due to abundant seed banks in invested regions. The amount of agricultural residues available was calculated from the well-accepted norm that for every dry tonne of cane sugar, grain (e.g. maize, wheat) or seeds (e.g. sunflower), roughly a tonne of cellulosic residue is produced on a dry basis.

It was furthermore projected by Marrison and Larson (1996) that an additional 67 Mt/annum energy crops can be cultivated on only 10 % of available land, excluding cropland, forest land and wilderness areas. The approach taken by these authors involved estimating energy crop yields (t/ha per annum) based on the mean of annual precipitation measurements. It should be noted that the production potential of biomass residues (wood, agricultural and grass) is broadly distributed in South Africa, with the greater potential towards the eastern third of the country. The non-crop, non-forest, non-wilderness land category upon which the Marrison and Larson study was based, includes land that is now devoted to livestock production. Thus, relatively low fractional utilization of this land (e.g. 10 %) is probably most appropriate to consider, and there is a need to analyze compatibility of integrating energy crop and livestock production at a local level in light of cultural as well as economic factors.

It is interesting to note that if about 11 % of South Africa's total land mass of 120 million hectares are used for biomass production at a yield of 5 t/ha, the required 67 Mt/ha can be reached readily. The same yield can be achieved if about 20 % of land is used at a moderate yield of 3 t/ha. When studying the vegetation map of South Africa published by Mucina *et al*. (2005), it is apparent that grasslands cover more than 20 % of South Africa's surface. Careful management of natural grasslands, or more intense management of high-yield perennial grasses in non-food regions in South Africa (Figure 23.2), may also achieve the projected 67 Mt/ha suggested by Marrison and Larson (1996). This would require close collaboration with environmentalists and agronomists to ensure sustainable management of these native resources.

Furthermore, concerted efforts by plant biotechnologists would be required for breeding of new energy crops, for instance high content of total fermentable sugars and/or high biomass yields under local conditions. Sugarcane researchers are already working towards developing high biomass yielding sugarcane varieties that produce high yields of lignocellulosic fibres in addition to sucrose. Sugarcane yields of 100 – 200 t/ha are within reach (Prof. Frikkie Botha – personal communication) and sugarcane can be considered one of the energy crops of the future. Considering either the use of natural perennial grasses or dedicated energy crops (such as whole-plant sugarcane), enough land will still be available for food production and conservation. Although this is a South African-specific scenario, much of the same principle will apply for most of the SADC countries that use less than 50% arable land for food production, and that have vast grassland and woodlands available.

When considering the use of 50-70 % of this plant biomass with advanced biochemical and thermo-chemical processes, South Africa could very well exchange the bulk of is current liquid fossil fuel with renewable biofuels. Furthermore, producing bio-ethanol from starch-based substrates using first generation technologies does not score well due to marginal energy balances (+27%) and negative life cycle impacts. On the other hand, the production of biofuels from lignocellulose scores well on environmental aspects (energy balances of +70 % and positive life cycle analyses), energy security and social upliftment, but the cost of processing remains prohibitively high. It is important to benchmark biofuel production against the energy balances of fossil fuels from crude oil (-18 %) and electricity from coal (-200 %) (Dale, 2008).

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Why considering lignocellulosics for the production of biofuels?

First of all, cellulosic biofuels will be primarily made from non-food plants, which could lead us out of the labyrinth of the food versus fuel debate. However, lignocellulosics have much more to offer. These include:

i. The plant biomass yield per hectare could be substantially more than for traditional food crops.

ii. Less fertilizer would be required and these plants could be more drought tolerant, particularly if perennial plants are used with established root systems to survive winter periods and to better absorb limited water from the soil.
iii. Lignocellulosics could provide orders more plant biomass than food or vegetable oil crops together.
iv. The energy gained per cost for cellulosics is much higher than for traditional biofuel crops.
v. Even although cellulosic biofuel production may utilise some fossil fuels, there is still a positive displacement of fossil fuel in the overall life cycle compared to conventional fuel production.
vi. Natural vegetation could be responsibly used where possible, not threatening biodiversity devastation.
vii. If clearing of natural vegetation is limited, biofuels production should start from a carbon-neutral basis, as opposed to monoculture crops where a major carbon debt is created by deforestation, or burning of natural vegetation to clear land.

Although plant biomass provides an attractive alternative for the production of biofuels, intelligent use of lignocellulosics is absolutely crucial! Careful consideration should be paid to all issues relating to a potential threatening of food production, striving to positive life cycle and energy balance analyses, protecting of biodiversity and natural vegetation should be given and overall reduction of GHG emissions to combat climate change would be imperative. Therefore, whole plant usage and the integration of all value chains (energy, food and animal feed) should be ensured.

NEXT GENERATION TECHNOLOGIES FOR TOTAL BIOMASS CONVERSION

Lignocellulose is globally recognized as the preferred biomass for the production of a variety of fuels and chemicals, resulting in the creation of a sustainable chemicals and fuels industry, with significant benefits in agricultural development. Lignocellulosic material comprise of three major components, namely cellulose, hemicellulose and lignin (Figure 23.3). Both cellulose and hemicellulose are polymers of fermentable sugars, with glucose and xylose as the major constituents, whereas lignin is an amorphous polymer of aromatic components with a high energy content, however, containing no fermentable sugars.

Lignocellulose represents the most wide-spread and abundant source of carbon in nature and is the only source that could provide a sufficient amount of feedstock to satisfy the world's energy and chemicals needs in a renewable manner. Besides the lignocellulose produced as agricultural wastes in the grain-based industries, Southern Africa also has strong biomass-based industries in sugar production and the paper-and-pulp industry, thereby providing widespread availability of this renewable resource.

Lignocellulose can be converted to fuels and chemicals by a combination of biological and thermochemical processing. Biological processing involves the hydrolysis of cellulose and hemicellulose into fermentable sugars for use in fermentation processes, while typical thermochemical treatment would involve gasification, combustion or pyrolysis to convert lignocellulose into high-value energy or chemical products. The major technical barrier to the biochemical conversion of the cellulose and hemicellulose components of lignocellulose is the recalcitrance of lignocellulose to biological degradation, which affects downstream product yields and overall economics.

Lignocellulose Conversion Technologies

The preference for lignocellulose as a future resource for biofuels (ethanol) production stems from its widespread availability, lower cost per energy-unit than starch, and overwhelmingly positive energy balance that is superior to starch. However, current lignocellulose-to-bioethanol processes are not deemed economically viable without government subsidies, thus requiring low-cost substrates, such as agricultural bio-wastes available locally, as well as technological developments to reduce processing costs.

Biochemical conversion of lignocellulosics to ethanol

Pre-treatment technologies need to be matched to the substrate and hydrolysis processing, as its efficiency affects the overall process economics. Enzymatic hydrolysis of pre-treated lignocellulose has recently been improved by the development of commercial cellulase enzyme cocktails dedicated to bioethanol production by the industrial enzyme giants Genencor (now part of DSM) and Novozymes. Processes utilizing these enzymes need to be developed for each type of lignocellulose substrate that can be utilized in Southern Africa, considering the need to optimize pre-treatment technologies according to the particular feedstock, and to develop processes that have the best overall economic feasibility. Methods for lignocellulose pre-treatment/fractionation are available, but have not been optimized for local substrates and novel African bio-energy crops.

The laboratory of Prof. Van Zyl has a world-leading effort in the development of yeast strains capable of producing a cocktail of cellulase and hemicellulase enzymes required for lignocellulose hydrolysis. These yeast strains will eventually be able to directly convert pre-treated lignocellulose into ethanol and other fermentation products in a one-step process, called consolidated bioprocessing (CBP). This is achieved via the introduction of enzymes in yeast that allows the CBP organism to hydrolyze the cellulose and hemicellulose fractions to fermentable hexoses and pentose, which can subsequently be fermented to ethanol via the introduction of pentose fermenting pathways (Figure 23.4). The development of these yeast strains have progressed very well and will avoid most of the costs associated with using commercial enzyme cocktails and having dedicated hydrolysis unit operations.

Lignocellulose thermo-chemical processes

Thermo-chemical conversion of lignocellulosic biomass raw materials, together with wastes from biological processing, into liquid biofuels can be performed by various pyrolysis and/or gasification processes. Pyrolysis of lignocellulose involves processing of biomass by heating for a few seconds to about 400-500°C in the absence of O_2, followed by rapid cooling, either under atmospheric pressure or vacuum, resulting in thermal cracking of the polymeric structure of biomass, with resultant conversion into gaseous, liquid ("bio-oil") and char products. Pyrolysis processes can be optimized for the production of liquid bio-oil for use in industrial heating and electricity generation.

Gasification of biomass, pyrolysis products or lignin-rich residues from biological processing can provide synthesis gas (syngas) for conversion to liquid biofuels. Gasification requires higher temperatures for longer periods in the presence of O_2 to primarily yield syngas with high energy content. This syngas can be used in a variety of synthesis processes to produce methanol, dimethylether or a range of fuels through Fischer-Tropsch (FT) technology. South Africa is the currently the world's largest user of FT-technology in the industrial plants of Sasol for the production of fuels and chemicals from coal gasification. Gasification of biomass-based resources can contribute substantially to the production of biofuels in such facilities.

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The major technical challenges associated with pyrolysis concern the effect of raw materials and pyrolysis conditions on the yield, quantity and commercial value of products. Products from fast pyrolysis of biomass (i.e. bio-oil and char) can be mixed to form an energy-dense "slurry" that can be used as an efficient feedstock for syngas production in a gasification plant. The slurry comprises only 50% of the transport volume of the raw biomass with the equivalent energy content. Gasification of both the pyrolysis slurry and native biomass requires particular process optimization due to the increased reactivity of biomass in comparison to coal, as well as the substantial differences in product composition. "Blended" fuels and chemicals can be produced directly from the syngas resulting from co-gasification of coal and slurry. Similar approaches to pyrolysis and gasification of lignin-rich residues from biological processing of lignocellulose will be investigated.

Since fast pyrolysis units can handle smaller quantities, for instance 100 000 ton biomass/annum, they can be decentralized to areas with concentrated woody material. Woody material can be converted to bio-oils, which are dense (1.2 kg/litre), pump well, ignite and burn readily when atomized. It can be readily transported to larger refineries in the area, for e.g. PetroSA's Mossgas in the South Cape. Unfermentable products from bioethanol plants can also be converted by fast pyrolysis. Bio-oils or biogas can directly be used to generate electricity or replace the usage of crude oil or electricity in large industrial boilers or those used at hospitals, for example.

Integrated production of biofuels and high-value chemicals in a biorefinery

The economics of the conversion of starch, sugar, lignocellulose and vegetable oil raw materials into biofuels can be improved by the integration of various processing technologies in a single production plant, or "biorefinery", based on the conditions in a particular local industry and region (Figure 23.5). Such a biorefinery is built on the example of an oil refinery where a range of fuel and high-value chemical products is produced from crude oil to achieve optimal profitability. In the case of biofuels production, such an integration of processing is of particular importance due to the current dependence of commercial undertakings on government incentives. In most countries, including the USA, government incentives, subsidies and regulations are essential to keeping the biofuels industry commercially viable. Biorefineries represent a technological solution that can substantially improve economic feasibility, especially considering the highly volatile nature of agricultural raw material costs and market prices for transportation fuels due to exposure to international economic and political pressures. It is likely that the future global market for biofuels will be exposed to similar volatility as the current crude oil markets, with substantial economic impacts for the industry internally and externally.

The generation of a fermentable sugar stream that can be utilized in any number of fermentation processes for the production of valuable proteins, metabolites or microbial biomass, is central to the production of bioethanol from any of the starch, sugar or lignocellulose raw materials. Fractionation of raw materials can similarly increase the range of products, such as from wheat grains (wet vs. dry milling) and biodiesel production, if sufficient volumes of vegetable oils can be extracted from raw materials for ethanol production. Biological processing of biodiesel wastes also represents opportunities for additional fuels and chemicals production. The integration of thermo-chemical processing can substantially increases the range of chemical and fuel products from such a biorefinery, especially by the production of bio-oils through pyrolysis and the combination of gasification with FT synthesis. Some by-products from the raw material, such as wheat bran, may also be of use in producing thermal energy or green electricity. The range of feasible products and processing options is also largely dependent on the range of substrates to be utilized in a particular facility.

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It is evident that exploitation of the full potential of a biorefinery for fuels and chemicals production requires the design of a production plant that can utilize a range of substrates and convert these to a range of products. Of particular importance is designing a process with the necessary processing flexibility, or "optionality," to provide for adaptation of processing according to changing economic cycles, thus improving longer-term profitability.

Evolutionary transition to cellulosic biofuels production

Progress from agricultural food production and first generation technologies for bioethanol and biodiesel production to second generation technologies don't need to be a revolutionary path, but rather an evolutionary path (see Figure 23.6). Food and first generation biofuels are already produced from sugar, starch and oil-rich food crops. When second generation technologies come to fruition, the appropriate entry point could be the use of agricultural and forestry residues. This would allow the roll-out of the necessary technologies and establishing biofuels value chains. Simultaneously, agronomists and environmentalists can assist in identifying energy crops and how to utilising intruder plants in a cost-effective way.

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South Africa's potential to produce biofuels from second generation technologies

When considering the potential plant biomass production capacity of South Africa as highlighted in Table 23.1, and assuming the necessary second generation biochemical and thermo-chemical technologies can be successfully developed, Figure 23.7 compares the potential biofuels production from agricultural and forestry residues, invasive plants and energy crops, in relation to the current fossil fuel usage of 20 BL/annum and the Industrial Biofuels Strategy's target for 400 ML/annum.

The conversion of only 70% of agricultural and forestry residues, as well as invasive plants, can already deliver 25% of the liquid fuel needs via biochemical processes* and 28% (upgrade of only the bio-oil fraction**) or 36% (total conversion to biofuels) via thermo-chemical processes of the total liquid fuel needs, which represent a 12 – 30 fold increase to the current Industrial Biofuels Strategy target. When adding the potential production of energy crops, and only 50% usage of this material for biofuel production, a further 65%, 72% and 95% of the total liquid fuel needs can be met by biochemical and thermo-chemical processes, respectively. Even if the full capacity of second generation biochemical and thermo-chemical technologies cannot not be utilized in the next 10 years, biofuels could make a considerable contribution to foreign

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* It should be noted that only the energy available in the polysaccharide (cellulose and hemicellulose) fractions of biomass is converted to ethanol, whereas at least 40% of energy is retained in the non-fermentable fractions (lignin, waxes and resins).
** It is also important to note that only about 55% of the original energy present in biomass is captured during upgrading of only the bio-oil fraction with zeolite as catalyst (Huber *et al.*, 2006).

exchange savings, boosting local agriculture production and providing additional markets and revenue for farmers, help generate employment and local economic development opportunities in rural areas and assist in reducing greenhouse gas emissions and preservation of the quality of atmosphere.

Environmental sustainability

Notwithstanding the potential of second generation technologies, we should learn from the lessons and mistakes of first generation technologies, such as high fertilizer usage (causing the expanding dead zone in the Mexican Gulf), low energy gains and deforestation (as taking place in Malaysia for palm oil plantations) that accompany first generation biofuels. Although second generation technologies for the production of cellulosic biofuels should assist us in overcoming many of the limitations and disadvantages of first generation technologies, we should from day one do the necessary environmental impact studies and have a holistic approach that can ensure sustainability. It thus remains essential to, alongside the development of second generation technologies, develop tools for life-cycle analysis, environmental sustainability studies and economical modeling to place biofuels production on a stronger footage as currently being experienced with mounting criticism against first generation technologies.

SANERI CoER Biofuels Research Programme

In March 2007, Stellenbosch University was awarded the Senior Chair of Energy Research (CoER) : Biofuels and Other Alternative Clean Fuels by the South African National Energy Research Institute (SANERI). The CoER : Biofuels is led by the Research Chair, Prof WH (Emile) van Zyl at the Department of Microbiology, Stellenbosch University, together with a team of core members. The core members of the CoER : Biofuels are Dr Marinda Bloom (Department of Microbiology), Prof JH (Hansie) Knoetze and Dr Johann F Görgens (Department of Process Engineering) at Stellenbosch University, as well as Prof Harro von Blottnitz (Department of Chemical Engineering, University of Cape Town). The CoER steers a Postgraduate Programme in Biofuels striving to (i) develop human capital with a strong scientific and engineering training, (ii) develop and establish technologies for commercial application, (iii) interacting with South African experts from industry, businesses and NGOs, and (iv) staying abreast with latest technologies and research through extensive international collaboration networks.

The vision of the CoER : Biofuels RandD programme is to focus on the technological interventions required to develop commercially-viable value chains for second generation lignocellulose conversion to biofuels in South Africa. This will assist South Africa to become a technology- and services-provider to biofuel producers in Africa, where neighbouring countries have substantially better biomass potential than South Africa. The programme builds on existing expertise in feedstock development, biological processing, bioprospecting, yeast biotechnology and non-petroleum hydrocarbon processing. As it is not possible to predict which technology will work better on different lignocellulosic feedstocks, the CoER will focus on second generation technology development looking at both biochemical (fermentation) and thermo-chemical (pyrolysis and gasification) processes. It is also important to note that biochemical and thermo-chemical processes for lignocellulose conversion to liquid biofuels have comparable efficiencies and economics.

The CoER specifically focuses on developing (i) second generation technologies for the one-step fermentation of starch to ethanol; (ii) the use of lignocellulose as feedstock for biofuels production by biochemical and (iii) thermo-chemical conversion; (iv) process modelling for integrating biofuels and high-value chemicals production in biorefineries; and (v) costs and life-cycle analyses to evaluate the environmental and economic impacts of these technologies. All together, valuable inputs will be acquired that can help determine the commercial feasibility of second generation technologies for lignocellulose conversion.

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24. Biofuel Production in Southern Africa: What Could be in it for Smallholder Farmers and the Environment?

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Abstract

Over 60 % of the population of SADC countries are in rural areas, where they earn a living principally from agriculture. Most of the SADC countries with the exception of South Africa are perennial food importers yet most of these countries' economies are agriculture based. For some of these countries, agriculture contributes as much as 40 % to the national GDP. Food insecurity has been caused by factors such as increasing frequency of drought, growing poorly adapted crops (particularly maize), high input costs, poor marketing systems and pricing policies. There is a need to promote alternative cash crops that are better adapted to the many limiting environmental factors of southern Africa and offer farmers an opportunity to earn income in environments where such opportunities are decreasing. The global drive towards clean energy has brought in alternative cash crops such as *jatropha* for bio-diesel and revivification of sweet sorghum production, this time, as a dual purpose crop; for food and bio-ethanol. The potential for biofuel production is particularly large in southern Africa, where high yield potential and lower costs for land and labour, which dominate the cost of production, in the developed countries provide an economic advantage that is hard to match. Concerns have been raised that energy crop production could contribute to food insecurity in rural areas in particular and nationally because land that would otherwise be used for food production would be diverted into growing of dedicated energy crops. SADC countries currently cultivate between 5 and 27 % of their potential agricultural land leaving vast areas fallow or idle. There is therefore likely to be a greater avoidance of conflicts with land use for food and feed production in SADC countries. Production of biofuel could reduce countries' fuel import bills, increase income of farmers, and create jobs and environmental benefits in a region afflicted with decades of natural resource degradation.

Keywords*:* Biofuel, southern Africa, smallholder farmers

Introduction

Over 60% of the population of southern African countries live in rural areas, where they earn a living principally from agriculture (Table 24.1). The percentage contribution of agriculture to the national GDP is up to 40 % in some of the countries. This therefore makes agriculture an important vehicle of achieving the millennium development goals (MDG). A productive and profitable agricultural sector is thus, a necessary component in meeting the MDG. Agriculture has a direct and indirect links to most of the MDGs. A productive and profitable agriculture will reduce the proportion of those suffering from extreme poverty and hunger (MDG 1), through increased income and improved nutrition. Increased income among the rural resource poor farmers realised from growing profitable cash crops would in turn lead to more children achieving primary education thus meeting MDG2. Profitable agriculture contributes to reduced child mortality (MDG 4), improved maternal health (MDG 5) and combating HIV/AIDS (MDG 6) by increasing diversity of food available and making financial resources generated available to manage illnesses. It has often been reported that the poor and food insecure households are most dependent on agricultural income sources, deriving almost three quarters of total income from agriculture.

Table 24.1: Land use summary for SADC countries and other selected countries

Country	**Total land area** (10^6 ha)	Forest Area (10^6 ha)	% Forest area to total land area	Agricultural Area (10^6 ha)	% Agricultural area to total land area	Cultivated Area (10^6 ha)	% Cultivated area to total land area
Angola	124.7	69.8	56	57.6	46	3.6	2.9
Botswana	56.7	12.4	22	26.0	46	0.4	0.7
D.R. Congo	226.7	135.2	60	22.8	10	7.8	3.4
Lesotho	3.0	-	-	2.3	77	0.3	11.0
Madagascar	58.2	11.7	20	27.6	47	3.6	6.1
Malawi	9.4	2.6	27	4.4	47	2.6	27.5
Mauritius	0.2	-	-	0.1	56	0.1	52.2
Mozambique	78.4	30.6	39	48.6	62	4.6	5.8
Namibia	82.3	8.0	10	38.8	47	0.8	1.0
South Africa	121.4	8.9	7	99.6	82	15.7	12.9
Swaziland	1.7	-	-	1.4	81	0.2	11.2
Tanzania	88.4	38.8	44	48.1	54	5.1	5.8
Zambia	74.3	31.2	42	35.3	47	5.3	7.1
Zimbabwe	38.7	19.0	49	20.6	53	3.4	8.7
Brazil	**845.9**	**543.9**	**64**	**263.6**	**31**	**66.6**	**7.9**
India	**297.3**	**64.1**	**22**	**180.8**	**61**	**169.7**	**57.1**
United States	**915.9**	**226.0**	**25**	**409.3**	**45**	**175.5**	**19.2**

* Agricultural areas include temporary and permanent pastures, and areas under permanent crops and temporary crops. The figures do not provide any indication of the suitability or availability of the land for particular purposes.
** Cultivated areas include areas under permanent crops and temporary crops.

Climate Change

There has been a significant shift in the staple food crops, with the production and consumption of the drought tolerant millets (*Eleusine coracana* and *Pennisetum glaucum*) and sorghum (*Sorghum bicolor* L.) for example, declining and being replaced by the now ubiquitous, but less adaptable maize (*Zea mays* L.). The shift to maize has been attributed to a host of factors that include changing urban preferences, subsidies, food aid, and the ease of processing of maize into maize flower. This has limited the economic opportunities for poor farmers in dry land areas, where sorghum and millets are the most adapted crops. They require less water and nutrients compared to maize. Finding alternative economic uses of sorghum for example could provide small-scale farmers in dryland areas with alternative sources of income particularly in a region where options in agriculture are limited. The greater part of southern Africa is too marginal for maize production without irrigation. The region as a whole is one of the most vulnerable regions in the world to climate change (Kandji *et*. *al*., 2006). Furthermore, most of the climate models predict that this region will even become a lot warmer and drier, with more frequent and severe droughts, interspersed by more severe flooding. Annual precipitation is expected to decrease by 10 percent, while temperatures are expected to increase by up to 2.5ºC (Ragad and Prudhomme, 2002). Unpredictable rainfall has often led to food shortages in Zimbabwe, Swaziland, Zambia, Malawi and other neighbouring countries in recent years. Unless there is a shift in the choice of crops, continued maize production will only exacerbate the problem of food insecurity in southern Africa. Kandji *et al*. (2006) pointed out that because only a small area in southern Africa is suitable for dryland maize, the government policies that put reliance on maize for national food security has continuously put southern Africa in a precarious food situation. Maize, a highly water and nutrient demanding crop compared to sorghum, requires 8,000 m^3 of water per hectare compared to sorghum which requires half of that figure. Although CIMMYT made significant strides in developing maize cultivars that are tolerant to both drought and low fertility (CIMMYT, 2003), the frequency and severity of droughts in southern Africa remains a big challenge to overcome.

Although sorghum is a highly adaptable crop to many parts of southern Africa, its use as a food source has steadily declined in preference for maize. The production and marketing of sorghum has been hampered by several factors that include lack of incentives to producers, and lack of profitable markets for the sorghum grain. Even with introduction of high yielding hybrid varieties in the last few years by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), production has remained low as volatility of domestic staple food markets continue to discourage any investments in this crop. One could argue that if high value products, with a reliable market and also attracting credit could be developed from sorghum then perhaps the production of this crop could improve.

This being the case therefore, there is a need to seriously look at alternative and profitable uses of sorghum, a crop better adapted to the many limiting environmental factors that characterise the small-holder farming areas of southern Africa. Such uses will offer resource-constrained smallholder farmers, an opportunity to earn an income in environments where such opportunities are getting fewer by the day.

Biofuels: New Crops – New Market Opportunities

The need to reduce global warming caused by greenhouse gasses produced from burning fossil fuels (petroleum), depleting oils reserves, the rising import petroleum bills and the need to reduce dependence on external supplies have all combined to create opportunities for the development of alternative crops and also the revivification of abandoned crops such as sorghum for biofuel that can be cashed on by resource poor farmers. Of the world's 47 poorest countries, three are in southern Africa, and all three import all their oil. These countries have substantial agricultural land base and with the right approach, can grow highly productive energy crops. There are more than a dozen cash crops that can be grown as feedstock for biofuel production in southern Africa; they include traditional annual crops such as sunflower (*Helianthus annuus* L.), soybean (*Glycine max* L), groundnuts (*Arachis hypogaea* L.) and cotton (*Gossypium hirsutum* L.) for biodiesel; maize (*Zea mays* L.), sweet sorghum (*Sorghum bicolor* L. Moench) and sugarcane (*Saccharum officiarum*) for ethanol. Cassava (*Manihot esculenta* Crantz), is a biennial crop, which is currently grown as a food crop in northern Mozambique, Malawi and Zambia. It has a strong potential as a feedstock for ethanol production as well. Among the perennial tree crops, potential biofuel crops for southern Africa include jatropha (*Jatropha curcas*), pongamia (*Pongamia pinnata*), and moringa (*Moringa oleifera*).

The biofuels, produced from agriculture biomass provide sustainable and eco-friendly energy options that foster environmental sustainability (MDG 7) and offer enormous opportunities to improve the level of smallholder subsistence farmers who depend on agriculture for their livelihoods (Reddy *et al*., 2007). The research and development on biofuel is also giving new global, regional, national and local public-private partnerships for development (MDG 8) as evidenced by the research and development being done by private companies on bio-energy.

Even if a market was to develop for maize as a biofuel feedstock in addition to food, the low and erratic rainfall, poor soil fertility, and high costs of farm inputs such as fertilisers and chemicals would still hamper its production. If maize was adapted, one could argue that viability problems that have dogged its production in the past could be resolved by the anticipated higher prices from biofuel producers as has happened in the USA where maize prices have more than doubled in the last few years due to the buoyancy in biofuel. For much of southern Africa, however, dry-land maize is a wrong crop altogether for much of southern African, which is dry. A good crop for small holder farmers of southern Africa must be adapted, must have a high value or reliable market, must attract credit and above all must be a low input crop, particularly fertilisers which are very expensive compared to Europe and North America.

Sweet sorghum, a type of sorghum has strong potential as it is drought tolerant, and produces grain while ethanol is produced from its sweet stalk. Sweet sorghum is similar to grain sorghum but has a sugar-rich stalk comparable to sugarcane. For those who advocate for *food first*, then sweet sorghum fits well into their model or slogan.

Sweet sorghum for bioethanol

Sorghum is native to sub-Saharan Africa, where it has been cultivated since time immemorial. Sorghum has relatively high water-use efficiency of 310 kg water/ kg of dry matter compared to 370 kg water/kg of dry matter for maize (Chapman and Carter 1976). Besides the higher water use efficiency, sorghum is very drought tolerant and therefore can be successfully grown in many parts of the region, where maize, the staple food crop has persistently failed to thrive. Sweet sorghum is a type of sorghum, which until recently was mainly cultivated for its sweet stalk. The advent of bio-ethanol production from the sugar-rich stalks of sweet sorghum offer new market opportunities particularly for the risk-averse smallholder farmers as it does not threaten food and fodder value of sorghum. Available varieties of sweet sorghum today can be cultivated for its sweet stalk, grain, fodder and bio-ethanol.

There is documented evidence that it is more profitable (about US$50 per ha per season) to cultivate sweet sorghum compared to the traditional grain sorghum (Reddy *et al*., 2007; ICRISAT, 2007). Compared to grain sorghum, sweet sorghum generally has more rapid growth, higher biomass production, wider adaptation, and has great potential for ethanol production. Rainy-fed sweet sorghum hybrids have higher sugar yield (20 %) and higher grain yield (16 %) compared to non-sweet stalk-grain sorghum hybrids (ICRISAT, 2007).

The emerging biofuel needs, now offer great opportunities in terms of expanded and more reliable markets for sorghum for many southern African countries. Currently bio-ethanol is commercially produced from sugarcane juice in Brazil and maize in the USA with increasing quantities also being produced from sweet sorghum in India and the Philippines. Some few southern Africa countries (South Africa, Zimbabwe and Malawi) produce limited quantities of ethanol from sugarcane molasses. The sugarcane is however, entirely an irrigated crop grown on large sugar estates, so smallholder farmers have no cake in its production.

Sweet sorghum has a growing period of about 4½ months and its water requirements amount to 4000 m^3 (or 8000 m^3 over two crops) (Soltani and Almodares 1994). In comparison, the maize water requirements are twice that of sorghum. The cultivation cost of sorghum is also four times lower than that of sugarcane, while the cost of ethanol production from sweet sorghum is also cheaper than that from sugarcane and maize at prevailing prices (Table 24.2). In addition to sweet stalks, grain yield of between 2 and 2½ tonnes per hectare can be obtained from dry-land sweet sorghum crop ─ this can be used as food or feed. The stillage from sweet sorghum after the extraction of juice has a higher biological value than the bagasse from sugarcane when used as forage for cattle, as it is rich in micronutrients and minerals. These important traits, along with its suitability for seed propagation, and comparable ethanol production capacity compared sugarcane molasses and sugarcane juice makes sweet sorghum a viable feedstock for ethanol production.

Table 24.2: Comparison between sweet sorghum, sugarcane and maize as sources of ethanol

Crop	Sweet sorghum	Sugarcane	Maize
Crop duration	4 months	12 months	4.5 months
Water requirement	4,000 m^3	36,000 m^3	8,000 m^3
Biomass yield in (tonnes/year)	46*	50	6
Ethanol source	Juice, (Grain, Stillage)	Juice, molasses	Grain, (Stover)
Ethanol yield (litre/ha)	3160	6000	3220
Cost of cultivation ($/ha)	258	995	287
Cost of ethanol ($/litre)	0.08	0.11	0.09

Source: www.olade.org.ec/biocombustibles/documents/pdf17.pdf

**For sweet sorghum at least two crops could be harvested per year in some areas, thus doubling the typical biomass yield per crop of 46 tonnes/ha to 92 tonnes/ha*

There is evidence that sweet sorghum ethanol is cleaner than sugarcane ethanol, when mixed with gasoline. Additionally, the pollution level in sweet sorghum-based ethanol production has one fourth of biological oxygen dissolved i.e., 19,500 mg per litre and lower chemical oxygen dissolved i.e., 38,640 mg per litre compared to molasses-based ethanol production (Reddy *et al*. 2007). Thus, sweet sorghum offers good prospects for ethanol production both from the point of economics of production as well as adaptation and environmental protection.

Jatropha for bio-diesel

Besides the highly adapted sorghum, there is also evidence that tree crops are even more adaptable compared to most of the annual crops grown in the drier areas of southern Africa. This being the case therefore, there is a need to seriously look at alternative tree crops that are, perhaps better adapted to the many limiting environmental factors that characterise the small-holder farming areas of southern Africa. Among the tree crops, the most suitable biofuel crop for the resource poor, small holder farmers of the drought prone and drier regions of southern Africa could be *jatropha. Jatropha* is widely used primarily as a live fence by resource poor smallholder farmers throughout sub-Saharan Africa. The physic nut can potentially be grown along field boundaries (as live fences) and on contour ridges, intercropped with other agricultural crops, and if preferred as a classical plantation tree crop. *Jatropha* is well adapted to marginal areas with poor soils (low soil fertility, alkaline conditions and shallow or gravely soils), low rainfall and high temperatures, where it grows without competing with annual food crops, thus filling an ecological niche (Tigere *et al*., 2006). The seed yield of *jatropha* varies from 0.5 to 12 tonnes per year per hectare; depending on level of management, soil, nutrient, rainfall, seed source, age of the trees, etc. On above average sites, an average annual seed production of about five tonnes per ha can be expected (Tigere *et al*., 2006; Francis *et al*., 2005). Jatropha is largely a wild tree, but beginning with seed source selection and breeding, high yields could be realised. Compared to the other potential biodiesel crops, the biofuel yield potential of jatropha is second to the oil palm which however is not suitable for the southern African environment (Table 24.3)

Table 24.3: Yield potential of different oil crops per hectare and extractable oil.

Crop	Oil Content (%)	Litres/ha	Time to production (yr)
Tree crops			
Oil Palm	40-70%	7109.0	3-10
Avocado	10-30	2637.8	1-3
Jatropha	43-59	2806. 2	2-3
Pongamia	27-36	4040.9	4-8
Traditional field crops			
Soybean	18-20	449.0	0.35
Sunflower	25-45	954.1	0.4
Groundnut	40-55	1057.0	0.4
Cotton	8	225	0.4
Castor bean	25-30	800	1

Source: Fulton *et al*. (2004)

Jatropha exhibits characteristics that make it a suitable species as feedstock for biodiesel production; the seeds of this tree have a high oil yield potential averaging 40%, which is comparable to groundnuts, which, however is a high labour and energy demanding crop to produce. *Jatropha* has traditionally been grown on non-arable land usually as a live fence to protect crops from livestock (Tigere, *et al*. 2006; Mushaka, 1998a; 1998b). It is therefore likely not to compete with traditional food crops for land although highest yields will most likely be realized from fertile land and well managed stands. Unlike other traditional agroforestry trees that are usually browsed and damaged by livestock during the dry season, *jatropha* is not palatable to livestock and is actually currently used as a live fence.

While many sources of renewable energy sources depend on highly sophisticated industrial processes, technology and investment, bio-diesel production from *jatropha* feedstock is anchored in the primary sector and uses local technologies, which can easily be adapted for rural industries for the smallholder farmers (Francis *et al*., 2005). The seed cake that remains after oil extraction has been shown to be a very good natural fertiliser. It has properties that compare favourably with those of other organic fertilisers. It contains 5.7–6.5 % N, 2.6–3.0 % P_2O_5, 0.9–1.0 % K_2O, 0.6–0.7 % CaO and 1.3–1.4 % MgO (Francis *et. al*., 2005; Tigere *et al*., 2006). In terms of the basic nutrients of nitrogen, phosphorus and potassium (N, P, K), the press-cake is equivalent in fertility to chicken manure. Some studies have demonstrated the effectiveness of the press-cake as a fertiliser (Ghosh *et al*., 2007; Patolia *et al*., 2007).

Besides its potential use as high quality natural fertiliser, the press-cake may also have a potential for livestock feed. The press-cake contains approximately 6-11 % oil, 58-60 % crude protein (53-55 % true protein content) compared to 45 % in soya bean cake, and the level of essential amino acids with the exception of lysine is higher than the FAO reference protein level (Francis *et al*., 2005). The current drawback to its use as a livestock feed is its toxicity (phorbol esters, curcin, trypsin inhibitors, lectins, phytates). Although, some studies have shown that the press-cake can be detoxified to make an excellent livestock feed (Martinez Herrera *et al*., 2006), the cost-effectiveness of this approach is still debatable particularly on its applicability at smallholder farmer's level of operation. Also, the seed content of the toxins vary among different *jatropha* cultivars and seed sources (Makkar *et al*., 1997; Makkar *et al*., 1998; Martinez Herrera *et al*., 2006) ranging from undetectable in the Mexican 'nontoxic' varieties to over 6 mg per g kernel in a toxic variety forms, opportunities exist to develop and use nontoxic varieties to eliminate these "minor" drawbacks through research.

The other commercially marketable product made from *jatropha* oil is glycerine, a by-product of the *trans-esterification* process of making biodiesel from the *jatropha* oil. The glycerine is used to make a high quality soap, or on further refining is used in a range of products including cosmetics, toothpaste, embalming fluids, pipe joint cement, cough medicine, and tobacco (as a moistening agent). Up to 7% of *jatropha* seeds are made up of glycerine, which sells for up to $2,000 per tonne (Francis *et al*., 2005). The raw *jatropha* oil is also used to produce a soft, durable soap. The soap making process is simple and well adapted to household or small-scale industrial activity. Soap making takes place on a cottage industry scale and is a boon to the people concerned. The soap making technology is very simple, and is a real village technology with the only investment being a hand-operated press. Jatropha oil is a cheaper substitute for beef tallow that is used in soap making (Tigere *et al*., 2006).

Despite these excellent attributes, the full potential of *jatropha* remains a pipe dream. The growing and management of *jatropha*, either in smallholder farm size plantations or agroforestry systems is poorly documented and there is very little experience to share, especially in southern Africa. Consequently, growers are unable to achieve the optimum economic benefits from the plant as no one knows the best seed sources, the optimum spacing, fertiliser requirements, and its general management. On the other hand the markets for the different products have largely remained informal, while large markets have remained sceptical of the capacity of the sector to produce sufficient quantities to meet their industrial requirements. Consequently, the actual or potential growers including those in the subsistence sector do not have adequate information on which to make informed decisions. There is a need therefore to do more research to determine optimum soil requirements, rainfall, spacing, pruning intensity and nutrients requirements, under smallholder farming conditions.

India recently designated *jatropha* as one of its primary feedstock. In southern Africa two countries (Namibia and Zimbabwe) have officially identified *jatropha*, as their preferred crop for biodiesel as well. Although not officially designated in Malawi, Swaziland, Tanzania and Zambia, *jatropha* planting for biofuel production is already being actively promoted.

Economic benefits for Small holder farmers

With more than 60% of the population relying on agriculture, the potential to produce biodiesel on small holder farms presents a unique opportunity to bring previously economically marginalised communities into the mainstream economy. Small holder farmers have failed to get out of the vicious circle of poverty as the crops they have traditionally grown have failed due to the vagaries of the weather and when they do survive drought, have always attracted low prices due to poor marketing systems and pricing policies. The growing of biofuel crops is expected to improve the smallholder farmer's income as they will be able to access the more lucrative international prices for their produce.

The European Union (EU) goal of replacing 5.75 % of fossil fuels with bio-fuels by 2010 (and going up to 12 % by 2015 and 20 % by 2020) would require significant imports otherwise; the target cannot be met with domestically produced biofuels alone (www.ies.jrc.cec.eu.int/wtw.html). This has already created a market with no suppliers. While many sources of renewable energy sources depend on highly sophisticated industrial processes, technology and investment, bio-diesel production from jatropha feedstock for example, is anchored in the primary sector and uses local technologies, which can easily be transferred to the poorest countries.

Economic benefits for Southern African countries

For many countries in southern Africa, oil makes up a significant portion of gross imports, and therefore a drain on their economies. In some of the countries, oil imports are almost equal to the value of their annual trade deficit. The production of biofuel from crops in these countries will significantly reduce their import bills of fossil fuel, thereby releasing more money to other critical sectors of the economy such as health. As fossil fuel prices continue to rise, bio-fuel production, domestic use and trade will reduce oil import dependency and increase energy security.

Employment benefits

Biofuels hold the promise of contributing to rural development by creating jobs in feedstock production, biofuel manufacture, and the transport and distribution of feedstock and products. When correctly produced, biofuels have a potential to meet the MDGs (Dufey, 2007; Flavian and

Aeck, 2006). Biofuels have a potentially positive impact on agricultural employment and livelihoods. The World Bank estimated that biofuel industries require about 100 times more workers per unit of energy produced than the fossil fuel industry. The sugarcane-based ethanol industry in Brazil, for instance, already employs around one million workers (Moreira, 2005) and this number is expected to grow by 20 percent in the next five years. Most of these jobs are filled by the lower-skilled, poorest workers in rural areas (Macedo, 2005). Indonesia's biofuel sector already employs 1.5 million people. The Colombian government anticipates that every farming family engaged in bioethanol production will earn two to three times the minimum salary of US$4000 per annum once the national Bioethanol Programme is implemented (Etcheverri-Campuzano, 2002). Similarly, India's national mission on *jatropha* biodiesel project is expected to generate employment to the tune of 16 million person days/year for the poor.

It is estimated that for every 5,000 ha of *jatropha* planted about 4,000 job opportunities are created in planting (1,500) and maintenance (2,500). In the processing side, one job is created for every 20 hectares of biofuel crop. The production of *jatropha* and sweet sorghum will thus be expected to stimulate rural agriculture by generating employment opportunities that have been stagnant with the current traditional crops. Jatropha and sweet sorghum production can provide the scale of growth that many developing countries, particularly in southern Africa, require stimulating economic growth. The two crops "perfectly" fit the model of crops for development of sustainable enterprises (Benjamin and van Weenen, 2000).

Opportunity for Clean Development Mechanism projects

Another aspect that needs to be further explored is the possibility for southern African countries to attract Clean Development Mechanism (CDM) projects and investment under the Kyoto Protocol through biofuel production.

Environmental benefits

The production of bio-diesel from jatropha for example, provides an opportunity for farmers to earn Carbon Credits (CC) to sell to developed countries. *Jatropha* fixes up to 10 t/ha/year of CO_2. Income may be realized from the Trade of Emission Certificates of the CO_2 sequestered. Because jatropha can be grown on marginal and degraded lands, it provides an opportunity for land remediation and reclamation, arresting desertification and restoring depleted soils.

Food Crops versus Biofuel Production: the Food Security Question

Concerns have been raised that energy crop production could contribute to food insecurity in rural areas in particular and nationally because land that would otherwise be used for food production would be diverted into growing of dedicated energy crops. SADC countries currently cultivate between 5 and 27 % of their potential agricultural land (Johnson and Rosillo-Calle, 2007), leaving vast areas fallow or idle. There is therefore likely to be a greater avoidance of conflicts with land use for food and feed production in SADC countries.

For most of the resource poor small holder farmers in the marginal areas, food insecurity has been caused by the unfavourable weather patterns that have made cropping (maize) the biggest risk. Jatropha and sweet sorghum being drought tolerant will provide the farmers with the much needed cash to improve their food security.

Hazell and von Braun (2006) described scenarios in which the economic, environmental, and social benefits of bio-energy could be made more complementary. The first is to find ways to reduce the trade-offs between bio-energy crops and food production. One approach is to focus on food crops that generate by-products that can be used for bioenergy, of which sweet sorghum is an excellent example of. Its grain is harvested for food while the sugar rich stalks are used as feedstock for bio-ethanol production. Another way suggested by Hazell and von Braun (2006) is to develop and grow biomass in less-favored areas rather than in prime agricultural areas. This approach would benefit some of the poorest people, and again jatropha is a good example of the crop as it can be successfully grown on very marginal sites. The other approaches they suggested involve increasing the productivity of food crops so as to free up additional land and water for the production of energy crops and developing biomass crops that yield much higher amounts of energy per hectare or unit of water.

Current Initiatives in Biofuel Production in Southern Africa

As of December 2006, D1 Oils Plc, a UK-based global producer of biodiesel had just over 124,000 ha of *jatropha* planted or committed worldwide (11,201 ha in southern Africa; 49,101 in India and 63,754 in south-east Asia). In Zambia, D1 is planting an initial 15,000 hectares of *jatropha*, and the Zambian government has pledged a further 174,000 ha over the next five years. In central Zambia, another private company Marli Investments Ltd. has engaged 5,000 farmers in out-grower schemes in Kabwe, Kapiri Mposhi and Chibombo districts to grow jatropha (www.d1africa/zambia.php).

In Swaziland, D1 Oil plc entered into a MoU with the government of Swaziland for the roll-out and planting of *jatropha* on 20,000 ha of land, expanding to 50,000 ha. A further MoU signed between D1 and World Vision Swaziland gives D1 access to an additional 3,000 ha. The project is for the development of out-grower schemes in communities supported by World Vision, an NGO, which will result in benefits for the communities. D1 Oils has been operating in Swaziland since 2005 and already has 1,000 ha in the Croydon and Hluti areas. (www.d1africa/swaziland.php).

In Namibia, the Government recently concluded that *Jatropha* is the most economically and technically viable biofuel crop in the country. Consequently, a CDM project is establishing *jatropha* plantations in north-eastern Namibia (Kavango and the Caprivi provinces) were a planting target of between 63,000 and 72,000 hectares by 2013 is envisaged (Ford, 2007). The project involves local communities in a region affected by extreme poverty and will provide a sustainable income to some 3,500 families. The plantations have the potential to generate temporary Certified Emission Reduction (CERs) equivalent to about 8 tonnes CO_2 by 2012. (www.ecosecurities.com/GetAsset.ashx?AssetId=10008).

The Zimbabwe government recent commissioned a bio-fuel plant in Harare which uses sunflower, cotton seed and soya and *jatropha* as a feedstock. The plant has a capacity to produce

100 million litres of diesel per annum. To date, between 30,000 and 40,000 ha of *jatropha* have been planted to supply feedstock to the plant (Mr Abisai Mushaka, *personal comm*.). A new ethanol plant that uses molasses is under construction in Chiredzi and is scheduled to be completed by April 2008. It has a capacity to produce 40 million litres of ethanol per annum.

In its biofuel strategy document, South Africa has listed a host of crops that include sugar beet and sugarcane (ethanol), as well as rape seed, soyabean and sunflower (bio-diesel) that will be used as feedstock. This is based on existing crop production, but the strategy acknowledges that South Africa has to conduct research to develop other biofuel crops as well. A company in South Africa plans to construct eight bio-ethanol plants in the Free State, Mpumalanga and the North West provinces. Construction of the first plant in Bothaville began in 2006 and was expected to be completed by the end of 2007. The plant which was expected to begin production by the end of 2007 will be able to produce 473,000 litres of alcohol from 1,125 tons of maize every day or 158 million litres of bio-ethanol from 370 000 and 400 000 tonnes of maize per year (Ford, 2007). More than 100 000 ha of maize would be contracted at each of the eight plants i.e. 800,000 ha of maize (www.engineeringnews.co.za/article.php). This initiative could supply up to 12.5% of the country's fuel needs by 2015.

Drivers of Bio-energy production

Many countries have now formally developed policies on the production and use of biofuel that are designed to stimulate investments in the production of feedstocks (Dufey, 2006). Supportive government policies are essential to the development of modern biofuels as observed in pioneering countries such as Brazil over the past decades. Among the most important policies that have incentivized producers are; blending mandates, tax incentives, government purchasing policies, environmental compensation schemes, and support for biofuel-compatible infrastructure and technologies (Worldwatch Institute, 2006; Dufey, 2006; Dufey, 2007; Deepak Rajagopal David Zilberman, 2007). While private companies are already leading in the investment in biofuels in southern Africa, government policies remain silent and therefore are likely to be the main impediment to realisation of the potential of this new industry.

Conclusion

If southern Africa is to move out of the vicious cycle of food shortages precipitated by droughts, then government policies that promote maize alone need to change. Dry-land maize is not a suitable crop for much of southern Africa, and when seasons are favourable, the high cost of fertiliser still makes production uneconomic. The bio-fuel industry presents unique opportunities that are particularly favourable to this region. The potential crops for biofuel are highly suited to the region. A combination of extension and favourable government policies (Dufey, 2007) in the case of sweet sorghum and research in the case of *jatropha* will stimulate smallholder farm production of both sorghum and *jatropha*, which are suitable for smallholder farming systems. Being a dual purpose crop, sweet sorghum is particularly easy to promote even with NGO who advocate for *food first* approach. The European market created by the blending mandates have created a potentially big market that may be hard to saturate.

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25. Biofuels in Zimbabwe: Opportunities and Pitfalls

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Abstract

Biofuels are renewable liquid fuels produced from biological raw material often referred to as being carbon neutral, with life-cycle analysis of their production process showing the potential of net carbon dioxide emissions reductions. In Zimbabwe *Jatropha curcas* has been identified as a potential source of biofuel, an idea with potential, whose implications on rural livelihoods remains unexplored. The major objectives of the study were to assess the potential impact of biofuel production on food crop availability; possible increase of yields through clearing more land and/or irrigation; the environment and the best option for rural Zimbabweans to benefit from biodiesel production. Results show that over 50% of rural Zimbabweans do not have adequate land for crop production which is further compounded by low erratic rainfall and poor soil fertility, lack of purchasing power for agriculture input and fragmentation of the land holdings(mean size, 2.5-3ha). Live fences are a viable option giving an average of US$2 100/household/year. If all farmlands are fenced with *Jatropha* a total of 1 993 250 litres are produced per year. Chances of success are high, provided that a cautious approach is taken in the biofuels program which is characterized by many positive ecological, socio-economic and energy related aspects. The success of *Jatropha* hinges upon the need to meet and defeat challenges that hinder adequate understanding of the *Jatropha* plant in all the five agro ecological regions. Communal people should be encouraged to plant *Jatropha* on their degraded fields and use the residues as agriculture inputs. Zimbabwe should continue with its biodiesel programme as long as it does not involve displacement of locals by large companies. However, fears remain over the supplementation of valuable water resources to ensure optimum yields from the *Jatropha* tree and the expansion into forest lands.

Keywords: Jatropha, biofuel, biodiesel, live fence, food security.

Introduction

Biofuels are renewable liquid fuels produced from biological raw material representing a substitute for petroleum. Across the globe a diversity of crops are being used to produce biofuels: corn in USA; sunflower and rapeseed in Europe; palm oil, in Thailand, frying oil and animal fats in Ireland; *Jatropha curcas* in India and sugar cane in Brazil. Biofuels are often referred to as being carbon neutral, yet a life-cycle analysis of biofuel production process shows the potential of net carbon reductions of carbon dioxide emissions (Achten *et al.,* 2007). Some studies have shown that biofuels can produce more carbon dioxide than the fuel it saves. More efficient technological advances are being developed, but currently available processing and land-use trade-offs require that we consider the full implications of any biofuel program. Scientists have however questioned the benefits of biofuels by analyzing total environmental production costs (Fargione *et al.,* 2008; Searchinger *et al.,* 2008). Such costs include costs of deforestation as more land is cleared in response to growing demand.

Biofuels may be sustainable in some instances and destructive in others. Many countries are investing in crop based biofuels as they seek to substitute costly fossil fuels. There is a possibility that some important habitats are robbed of their ecosystem services as cultivation of feedstock becomes more attractive. The loss of old growth forests/woodlands and grasslands foregoes ongoing carbon sequestration resulting in additional emissions. Carbon savings from biofuels depend on the land use change being effected, type of agriculture practice, and type of feedstock production pathway (Achten *et al*., 2007). The degree to which biofuels may decrease carbon emissions when compared with fossil fuels depends therefore on the processing methods (Turner *et al.,* 2007) and the type and history of land used for cultivation (Smeets *et al.,* 2005; Achten *et al.,* 2007). Although biofuels have been herald for environmental gains, in order to conclude their advantage over fossil fuels, the full cycle should include sequestration from land use to processing and final usage. Social impacts must also be considered.

In Zimbabwe biodiesel production can save on foreign currency demand because the country is experiencing severe hard currency shortage, which has led to hyper-inflation and chronic shortages of fuel and other imported goods. *Jatropha* trees are productive for up to 50 years with an annual yield of 2.0 – 12.5 tonnes of seeds per hectare per year with one hectare yielding between 2.1 and 2.8 tonnes of oil per year (Duke, 1983). At a spacing of 2 m x 2 m, a total of 2,200 trees can be planted per hectare (Gaydou *et al*., 1982). After the first five years, the typical annual yield of a *Jatropha* tree is 3.5 kg of seeds per plant. About 4 kg of seed is needed to make a litre of biodiesel. Several methods can be used to extract the oil from the seed. Ninety one percent of the oil can be extracted with cold pressing. The oil is therefore an important raw material for local energy needs (IBRD, 2002). Press cake/ seedcake left after the oil is pressed from the seeds and can be composted and used as a high grade nitrogen rich bio-fertiliser. The glycerine is used to make soap. Various parts of the plant have medicinal value (Lele, 2004).

Zimbabwe is currently on a biodiesel campaign targeting 40 000 hectares for biofuel which is expected to yield about 100 000 000 litres of biodiesel per year. In Zimbabwe *Jatropha curcas* L. has been identified as a potential source of biofuel. The seeds produce inedible oil and the plant can survive in any environment. This has potential, but the implications on rural livelihoods and net carbon emissions remain unexplored.

The major objectives of the study were to assess the potential impact of biofuel production on food availability, food pricing and the environment by investigating: the impacts of potential biofuel production on food crop availability; possible shifts in agricultural practices that could lessen any adverse effects of biofuel production on net annual crop production and the economic consequences and implications of biofuel production on food.

Threats of biofuel production using *Jatropha curcas*

Food Security

The high demand for energy and the apparent enormous potential of biofuels are no guarantee that small farmers and poor people in developing countries will receive the benefits (von Braun and Pachauri, 2006). The continued expansion of biofuel production on productive land may have widespread effects on food security because biofuel production can displace crops or pasture in existing agriculture lands. Displacing current croplands is disastrous and creates an opportunity for food crisis. These global trends results in a food crisis in already stressed economies. Harris (2006) analysed the relationships between population, agriculture and the environment and showed that most of the developing countries will account for 95% of world population growth. There is need for an increase in agriculture inputs/unit of land because this level of population growth will need twice as much grain by 2025. Studies have already shown that the developing world would suffer food shortages in the future (Oxfam, 2007). If nations with surplus grain capacity decide to keep their grain for biofuels, then this is likely to create a crisis in the developing world. The study by Msangi *et al.* (2007) has warned of how a steady increase on the growing demand for biofuels could short change less economically developed countries (such as Zimbabwe) that depend on staples like maize to feed their populations.

Zimbabwe has been listed among 82 low income food deficit countries (LIFDCs). This is because ever since the drought of 1992/1993, the nation has not recovered the full capacity of grain storage reserves and therefore relied on imports to satisfy national grain requirements. The nation therefore will suffer from biofuel impacts of global food rise unless this is compensated by good exports. Biofuels are likely to create some competition with food crops in Zimbabwe unless they are planted on wastelands (unproductive) or abandoned farmlands and do not require inputs for growth.

Increased food prices

Meeting targets for biofuels will require large scale production of energy crops especially from the developing world. The rise in demand for biofuels especially in the developed world has become a threat to vulnerable people through exploitation and deterioration of food security (Oxfam, 2007). Biofuels have been identified as a major driver of food price increases. The price rise threatens food security of those already stressed. In the same briefing, Oxfam (2006) reported that a country like Zimbabwe may be threatened by global biofuel price trends. Doornbosch and Steenblik (2007) predicted food price increases of between 20 % and 50 % over the next decade if food crops are used for biofuels. Increases in biofuel crop prices is likely to also result in an increase in prices of other crops that compete for the same land or those whose ingredients are used in biofuel process. Biofuel production in relation to its benefits will put a heavy burden on the poor in most countries in Africa if left unmanaged. It has been stated that, setting aside land for biofuels could increase the price of everything that is agro based including beef and eggs (Brown, 2007). If we look at it from another angle food price increases are really caused by fossil fuel price increases rather than biofuel production. Figure 25.1 shows the relationship between oil price rise and food price rises.

Although Graham and Glaister (2002) and Sterner (2007) showed that biofuels might decrease overall energy prices which could increase energy consumption resulting in more emissions.

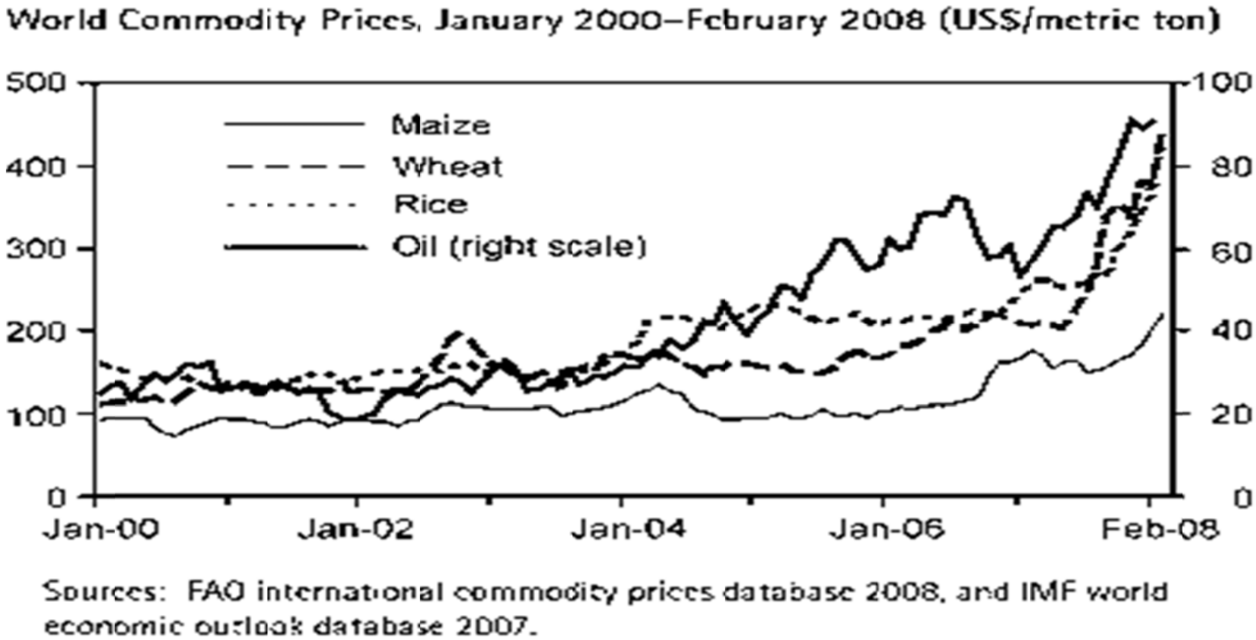

Figure 25.1: World food prices, January 2000 – February 2008 (US$/metric tonne) (Source; Von Braun, 2008)

Land Availability and Sustainability

Many countries especially in the developing world are now interested in biofuel production as they quest to create biofuel exports to the developed world. The demand for biofuels will grow by 170 % in the next three years and will contribute 25 % of the world energy needs in the next 15-20 years (Jumbe *et al.,* 2007). In support of this the UNDP (2007) showed that global production of biofuels have doubled over the past five years and they predicted that it is likely to even double in the next four years. Many countries have supported these growing figures through their national policies and rising biofuel targets for example Indonesia plans to increase its palm oil production by 406 % in 2025, the United states will use 28.4 billion litres of biofuels by 2012, Europe plans on 10 % biofuels by 2010 (http://www.worldchanging.com/), India and China have been making aggressive plans to increase biofuels production fourfold by 2020 and Southern Africa about 4 million km^2 will be converted to biofuels over the next decade. With growing population and rising income, pressures on natural resources will intensify, leading to more natural habitat destruction.

Recent investment assessments (Owens, 2006; www.sunbiofuels) have shown that southern Africa has the potential to supply world biofuel needs. These assessments however ignored traditional uses and biodiversity and environmental importance of the "available" land. The UN permanent forum on indigenous issues warned about the displacement of 8.33% of indigenous people in the developing world due to biofuel plantation establishment (http://mwcnews.net/content/view/14507/235) with 83% of those affected located in Indonesia. Negative reports on social impacts of biofuels have been published for Colombia (The guardian, 2007), Indonesia (Down to earth, 2007; World rainforest movement 2006), Tanzania (African Biodiversity Network, 2007), Malaysia and Brazil. Livelihoods are lost together with the land forcing people to migrate or take up lowly paid jobs as plantation workers. Those who choose to work in biofuel plantations are underpaid overworked and intimidated an aspect which is often ignored in the biofuels debate.

The effects of biofuel production in USA and Europe have also resulted in habitat destruction in the developing world (Hooijer *et al*., 2006). For example in Indonesia and Malaysia deforestation for biofuel accounts for 1.5% of overall deforestation of tropical rainforests (Hooijer *et al.,* 2006) and the Brazilian Amazon has been threatened by sugar cane and soybean production (Klink and Machado, 2005; Cerri *et al*., 2007). The Millennium ecosystem Assessment stated that agriculture is the greatest factor in ecosystem modification (Millennium Ecosystem Assessment, 2005) and it's clear that biofuels will require additional land resources or some form of intensification.

Opportunities of biofuel production using *Jatropha curcas*

The government of Zimbabwe (Ministry of Energy and Power Development) has drafted a policy on biofuels and plans to increase its coverage of Jatropha throughout the country. The Forestry Commission and The national Oil Company of Zimbabwe (NOCZIM) have undertaken a massive production of seedlings in recent years, largely in response to the need to meet growing biofuel demands. In Zimbabwe policy support for biodiesel feedstock production as a means of alleviating poverty and promoting energy efficiency will generate continued expansion and sustainability of biofuel production. Producing biofuels to substitute oil imports is likely to help reduce the oil bill. It is good that the Zimbabwean government is encouraging national participation in order to avoid more land being taken from mainstream agriculture for large scale export oriented production of biofuels. This move will reduce expropriation of profits out of the country. Apart from supply of seedlings NOCZIM provides credit facilities for plantation of biofuel plants, raising nurseries, establishment of seed collection and oil expelling centres and biodiesel manufacturing units. It is also assisting NGOs and other research organisations to spread awareness about non-conventional energy sources including biofuels through demonstration of alternatives and technologies. The major thrust is on biofuels grown on wastelands which have the lowest risk (Achiten *et al.,* 2007) using *J. curcas* which has a carbon dioxide sequestration of ±2.5 tons/ha/year (Francis *et al*., 2005). The biofuel programme in Zimbabwe is dependent on government subsidies, which can lead to market distortion and therefore may not indicate their actual costs.

Biofuels might decrease overall energy prices (Graham and Glaister, 2002; Sterner, 2007), save on expensive petroleum imports and can improve welfare of the poor if done transparently. Biofuels can generate a new demand for agricultural products, creating jobs in rural areas and increasing farmers' income through higher commodity prices. This dedicated poverty reduction programme organised by government and NGOs can indeed be a viable solution to improve the standard of living of the poor in Zimbabwe. In most parts of the world, the development and promotion of biofuels are mainly driven by agricultural sector and green lobbies rather than the energy sector but in Zimbabwe biofuel promotion is mainly driven by national energy sector. This shows that biofuels can have significant economic opportunities for small scale farmers if the production, transport and processing of seeds takes place in the rural areas. Rural communities can also derive income from the processing of biofuels, such as soap making, fertilisers etc.

The effect of rising prices of fossil fuels will heavily impact on oil importing countries such as Zimbabwe hence biofuels offer some relief on fuel import bill. In addition to prices, the government is showing interest in biofuels because they offer energy security, have a role on issues of trade balances, have potential benefits to rural livelihoods and have potential to reduce greenhouse gases. The uneven global distribution of oil supplies with 75 % in the Middle East, results in uncompetitive structures governing the oil supply. The volatility of world oil prices places countries like Zimbabwe vulnerable to supply disruption (Dufey, 2006). This vulnerability has been demonstrated by recent interruptions in oil supply from Russia to Belarus because of political disagreements. The utilisation of degraded lands for production of feed stock from perennial and woody species monoculture have greenhouse gas advantages over food based crops (Parrish and Fike, 2005; www.futureenergyevents.co/jatropha). Although some studies have indicated that biofuel production generates more greenhouse gas than fossils many have also indicated the benefits of biofuels when compared with fossils (Francis *et al*., 2005) though the extent of reduction of greenhouse gases is disputed (Sims *et al*., 2006; Farrell *et al.,* 2006).

The Zimbabwean biofuels scenario

Land ownership patterns in Zimbabwe vary from land owned by government, forest land, land under customary law as common property and private ownership. The communal area land holdings in Zimbabwe are so small such that the farmers may not be able to take advantage of the opportunities on the biofuels market. Only the newly resettled farmers and a few with large land areas (>4.0 ha) may benefit from the biofuel campaign. The landholdings are however stable from generation to generation governed by communal tenure system. The total cropland in Zimbabwe is 3 350 000 ha with rural land holdings ranging from <1.0 ha - > 4.0 ha per household. Each household has an average of six members. To have enough food they need a minimum of 3 ha of crop land per household (Bratton, 1987; Reh *et al.,* 1988).

If we use size of land holding as a basis for our analysis it means more than half of rural households do not have enough cropping land for food. If we expect then to cut a share of this land for Jatropha, then there will be a food crisis. If we assume they will use *Jatropha* as a live fence the expected yields from each land category are shown in Table 25.1. Due to land shortages, block plantations and large scale commercial plantations will only be viable for 12% of the rural population and those in resettlement and commercial farms. Therefore, possible interventions for biofuel feedstock are agroforestry practices in the form of live fences, boundary plantings and small scale plantations on unproductive lands. We analysed the advantages of using live fences.

Revenue for *Jatropha* seed sales is (€ 178/US$240 per tonne) (Biopact, 2007). Generally farmers can earn (US$96 - 3 000/ha/ year) depending on fertility of land and the amount of rainfall in the area. Yields vary from 2.1 – 12.5 tonnes per hectare while they vary from 2.5 – 3.5 t/ha for live fences (Lele, 2004; http://www.jatrophaworld.org/10.html).

Table 25.1 also shows expected revenues from live fences around farmland categories. The average revenue of $2 100 based on average farm size gives about US$131.25/individual in a household of eight people which is enough for two months at $4/day/person. If all cropland in Zimbabwe is fenced by *Jatropha,* a total of between 8 375 000 and 11 725 000 tonnes of seed is produced annually = 1 993 250 litres/year at 0.171kg/ha (0.8-1.0 kg per metre of live fence)

(Lele, 2004). Farmers can combine their seeds for marketing and save on transport and handling costs.

Table 25.1: The cropping land availability for rural Zimbabwe and the associated gains from live fences

Size of land holding (hectares)	**Percentage of households**	**Expected yield from *Jatropha* fence (t/ha)**	**Revenue/year (US$)**
<1.0	11-28	< 3.5	<840
1.0 – 2.5	45-50	3.5 – 8.75	840 - 2100
2.6-4.0	20-25	9.1 - 14	23786.4
>4.0	12	>14	>3360

With considerable incomes being generated by biofuel cultivation, the issue of competitive use of agriculture land will become increasingly relevant if land use for food crops is diverted for biofuel production. The farmers have no investment capital for agriculture inputs and most areas have low erratic rainfall. The soils are poor and heavily degraded and will need fertiliser to be productive, the mycorrhizal value in *Jatropha* roots helps in getting phosphate from *Jatropha* seedcake.

The quest for more productivity may motivate farmers to clear more land or improve yields through irrigation and fertilisation. These three options have serious environmental impacts including water scarcity, pollution of soils and water ways (World Watch Institute, 2006; Cook *et al.,* 1991) affecting biodiversity (NAS, 2007), carbon emissions and critical food crop reduction. Expansion of cropping land decreases habitats thus reduce ecosystem services offered by natural habitats. This has already been outlined for example in Malaysia (Friends of the earth, 2005) and in the United States (Marshal, 2007). For Zimbabwe, planting of Jatropha may be a viable option of diversity and security in the uncertain environment where soils are heavily degraded and agriculture inputs are beyond the reach of many. In Zimbabwe there is already a shortage of pastures due to overgrazing despite the fact that only 40% of the households own cattle.

Challenges

There are claims that *Jatropha* can grow in arid and semiarid conditions, in cool climates and in degraded lands. *Jatropha* yields are difficult to predict because in most cases there are given as a range (2.0 - 12+ tons/ha) making yield predictions difficult for investment calculations. There is a need for more research into the agronomy of *Jatropha* to determine the ideal climatic conditions which ensure maximum yields. There is also need for research on *Jatropha's* long-term impact on the environment which is critical for sustainable development. Research should focus on the cost/benefit analysis including environmental, social and economic costs/benefits throughout its life cycle.

It is possible to adapt our agriculture to changing needs of human kind by also harnessing the potential benefits offered by biofuels through the planting of *Jatropha* as a live fence or on degraded or abandoned lands. There is however need for appropriate technologies that will increase productivity of agriculture per unit of land or labour, to meet growing global demand for both food and biofuels. Economic viability of *J. curcas* production remains uncertain for farmers in all categories since annual seed yields and responses to management are still badly understood. Although it is said to grow in any ecological region the productive capacity and prescribed silvicultural practices for optimum yields is not clearly outlined for different ecological conditions. Research should also focus on effects of the seedcake on other plants and on the human health mainly skin contact and accidental ingestion.

There is need for the establishment of a proper collection system for seed and oil so that small scale farmers and landless collectors find it easier to travel to sell their seeds or oil. The provincial and district areas already chosen may need to be increased to lessen the distance. Similar distributive structures have worked well in other parts of the world.

Concluding remarks

Over 50% of rural Zimbabweans do not have adequate land for crop production which is further compounded by low erratic rainfall and poor soil fertility, lack of purchasing power for agriculture input fragmentation of the land holdings mean (2.5-3ha). Chances of success are high, provided that a cautious approach is taken in the biofuels program since it is characterized by many positive ecological (e.g. erosion control, soil improvement, soil stabilisation, sequestration etc.), socio-economic and energy related aspects. The success of *Jatropha* hinges upon the need to meet and defeat challenges that hinder adequate understanding of the *Jatropha* plant and its extraction and processing in all agro ecological regions. Zimbabwe should continue with its biodiesel programme as long as it does not involve displacement of locals by large companies. Communal people should be encouraged to plant *Jatropha* on their degraded fields and use the residues as agriculture inputs. More publicity and seed purchase centres are needed. The more this plant is exploited, the better for the environment and also for food production. If biofuels are irrigated, the water requirement will add pressure on water resources that are already stressed, or will soon be, in many places. Therefore, fears remain over the use of valuable water resources to ensure optimum yields from the *Jatropha* tree. The consequences of biofuels on food supply surely remain uncertain and hence should not be ignored but constantly monitored.

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26. Impact of Biofuel Production on Food Security: Strategizing for the Production of Physic Nut (*Jatropha Curcas*) in Marginal Areas in Ghana

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Abstract

Global interest in seeking alternative sources of renewable energy in response to climate change and rising oil prices is increasing. Use of food crops including maize (*Zea mays*), soybean (*Glycine max*), cassava (*Manihot esculenta*), sugar cane (Saccharum spp.), oil palm (*Elaeis guineensis*), groundnut (*Arachis hypogaea*) and coconut (*Cocus nucifera*) for industrial purposes including bio-fuels is underway in several countries. Non-food crops which have been targeted include physic nut (*Jatropha caucus*) and cotton (*Gossypium spp*.). Bio-fuel production is viewed as a good alternative source of energy since it may offer reduced demand for fossil-based fuels, a potential for creating new jobs and income generation among the rural poor, and reduced emission of greenhouse gases. Nonetheless, the United Nations has warned that without strict environmental regulations, cultivation of energy crops can result in negative impacts particularly on climate change and food production as well as irreversible consequences for agricultural biodiversity. It is in view of this that a global shift towards bio-energy crop cultivation calls for caution. In the past two years, there has been considerable debate on the use of bio-fuels with well-articulated points on the need to make the practice sustainable. This paper seeks to examine the arguments that have been advanced in favour or otherwise of large-scale crop/plant production for bio-fuel to meet gaps in supplies of petroleum, the implications for ensuring global food security particularly in developing countries and to identify factors necessary for designing a strategy to bring a balance between the provision of bio-fuel using physic nut without compromising food security in Ghana.

Keywords: Biofuel, Food Security, Ghana, *Jatropha curcas*

Introduction

Provision of alternative sources of energy to meet growing energy demands is fast increasing worldwide. The major forces behind this drive include increasing oil prices, exhaustion of oil fields and threats due to climate change (Sugrue and Douthwaite, 2007). Many developed countries have been focusing on biofuels to mitigate the impacts of fossil fuel price hikes and their dependence on oil imports (Chow, 2007) by promoting large scale production as well as setting targets to increase biofuel use in transportation (Sugrue and Douthwaite, 2007).

The competitive edge for biofuel production however seems to lie with developing countries that have favourable climatic and environmental conditions for plant growth, low labour costs, low energy input in agricultural production and hence low production costs for energy crops (Lamers, Mc Cormick and Hilbert, 2008).

Both food and non-food crops have been used as energy sources. While energy crops could help local farmers and boost the economies of these developing countries, there is the need to sustain the discussion in the interest of all stakeholders especially the poor farmers in these developing countries in terms of the long term effects on food production and the environment.

The issue thus boils down to two broad areas of biofuel production and food security and it may seem important to address the nature of the relationship between these two broad fields. This paper reviews arguments that have been raised on large scale plant/crop production for biofuel to meet gaps in supplies of fossil fuels, its implication for ensuring food security particularly in developing countries and suggests a strategy to bring a balance between biofuel production and food security.

Biofuel Production and Food Security Interactions

While biofuels may appear attractive, their production can result in food insecurity when farm-lands are converted to produce feedstock for fuel and other uses; large quantities of edible crops are diverted into ethanol; prices of other cereals increase indirectly following increases in prices of maize; forests and grasslands are cleared to make room for large biofuel crops plantations; and food surpluses which otherwise could bring market prices down are channeled into biofuel.

The UN warns that converting fields to the production of energy crops rather than food crops could reduce the quantity and variety of crops available for food thereby pushing up global food prices (UN-Energy, 2007). Sugrue and Douthwaite (2007) also noted that increases in food prices may be as a result of higher cost of production as modern agriculture is fuel intensive. In any case, surpluses which have had the effect of depressing the world price of grain have been removed from the market and converted to motor fuel. However the EU has argued that increase in food prices is due to climate change rather than use of grains in biofuel production (Makenete,Lemmer and Kupka, 2007) A thorough analysis of international agricultural commodity markets however shows the complexity of factors contributing to food inflation and include lower opening stocks (due to policies change in the EU and USA), increased demand especially from China and India, as well as drought and market inefficiencies (OECD-FAO, 2007).

To ensure a good balance between "biofuel production" and "food security" in southern Africa, Sugrue and Douthwaite (2007) recommended:

- No tax breaks and excise duty reduction on ethanol production from maize, wheat or sorghum or for biodiesel produced from canola or soybean,
- Concentration of land ownership and land access into farmer hands should not be employed in biofuel production,
- Government should develop contingency plans to ensure that undue hardship is not caused to the poor if the food and fuel prices they face rise more rapidly than their incomes,
- There is a need for the development of the biofuel strategy in a wider context than is currently apparent to include a wider use of product in other sectors and not transport

only.

Clancy (2007) also reiterated the need for a more integrated approach to biofuels including liquid biofuels, biogas and agricultural residues; an adoption of a demand-side perspective to energy planning; "fair-trade" biofuel development to improve the performance of producers and development of policies by countries geared towards improving the livelihood of the rural poor which could ensure poverty reduction in developing countries.

It could therefore be suggested that when biofuel crops are cultivated sustainably with appropriate mitigation of potential risks with food security and biodiversity factors underlying their production, it is likely to be a beneficial alternative to fossil fuels around the world, not just for transport but other uses as well.

Strategizing for Biofuel Production in Ghana

Although biofuels have been hailed as a good alternative to fossil fuels worldwide, especially in developed countries including Brazil, USA, Argentina, Germany and South Africa sustainability of production over long term still remains a major concern. This is because feedstock for the industry is dependent on food crops. Hence, they have all emphasized the need to diversify feedstock crops (Lamers, Mc Cormick, Hilbert 2007; Makenete, Lemmers and Kupka, 2007). Cultivation of non-food crops in developing countries with large agricultural sectors are currently gaining attention with some countries including Tanzania and India already encouraging cultivation of physic nut (*Jatropha caucus*). Information on biofuel demand in African countries is however scanty and so is knowledge of biofuel resources and production.

In Ghana, a major part of the land is already devoted to prime cash crops such as cocoa, oil palm, shea nut, cotton, mango and pineapple and food crops including maize, plantain and cassava. Although some of these crops have industrial uses and there have been calls recently to increase their cultivation in relation to increasing world prices, their diversion into biofuel production may bring about sharp conflicts in end-use. The cultivation of physic nut for biofuel production may seem a viable alternative. Hitherto this has been grown throughout the country for fence and also as a medicinal plant.

The crop is reported to do particularly well in the tropics and India has reported several instances of growing physic nut on marginal lands with success. The ability of the crop to encourage the restoration of degraded lands for agricultural use makes undisputable good logic for its cultivation on marginal lands. However, the success of the physic nut industry will rely on factors including land tenure, policy, research, processing and marketability. The government of Ghana has already expressed support for the development of locally based alternative fuel industries to substitute petroleum products (GNA, 2006) with a National Biofuel Bill already drafted. Approval of the Bill will enhance the formation of a network of researchers, producers, purchasers and processors as well as distributors of the biofuel.

Research in areas of uniformity of planting material, characterization of species available, as well as nutrient needs of the crop could boost cultivation to produce optimized yields. The most appropriate processing procedures, environmental impacts and potential land use conflicts with food crops as well as both international and local trade opportunities will also ensure viability and sustainability of the industry.

Adoption of alternate cropping systems complementary to other agricultural systems such as Agroforestry will enable the derivation of other environmental benefits from the cultivation of the physic nut. In this regard, the crop could be incorporated in contour vegetation strips to protect sloping lands from erosion as well as the embankments of water bodies or dams to reduce silting from runoff. The crop could also be used as live hedge to protect food and or cash crops as well as reforestation projects from grazing animals. Emphasis on small scale production with a purchasing chain to accumulate feedstock for processing plants may be a much easier objective to attain considering that fruiting is continuous except for the dry season. To optimize the production of physic nut to the rural poor, it is imperative that governments get involved in developing programmes to ensure a favourable environment for both domestic and international investors towards a sustainable industry. Biodiesel 1 Group, a local bioenergy company is working with the Department of Crop Science with assistance of British Council through the African Knowledge Transfer Partnership to develop high yielding varieties of *Jatropha spp*. for Ghana.

Conclusion

While there may be legitimate concerns that biofuel could compromise food security and adversely affect the environment, bioenergy crop production could also account for an important tool for improving the well-being of rural people if governments take into account environment and food security concerns. In view of this Ghana has been holding bilateral discussions with Brazil on the development of the industry locally. Brazil in particular has shown the importance of research in the biofuel industry with remarkable success.

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27. The Effects of *Jatropha Curcas*, L. Seed Cake Supplemented with Inorganic Nitrogen Fertilizer on Maize Production in Zimbabwe

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Abstract

A research study exploring the use of jatropha seed cake as a sole source of nutrients and in combination with inorganic N fertilizer was conducted on station at Henderson Research Station in Mazowe in the Agro-ecological Natural Region IIb of Zimbabwe. The experiment was located on a sandy soil site. It was carried out during the rainy season of 2006/2007. The study was conducted to determine the effect of jatropha seed cake on maize dry matter and grain yield. Three levels of jatropha seed cake were tested (0 kg ha^{-1} , 767 kg ha^{-1} and 1534 kg ha^{-1}) in combination with 3 levels of inorganic nitrogen (N) levels (0, 25kg/ha and 50 kg/ha N). The jatropha seed cake was applied at planting and the inorganic N was applied as topdressing at 6 weeks after crop emergence (wace). The control was 200 kg ha^{-1} Compound D (N: 7 %, P:14 % and K: 7 %) applied as basal fertilizer in combination with the three inorganic N fertilizer rates. Twelve (12) treatments were tested in the experiment and it was laid out as a 4 x 3 factorial arranged in a randomised complete block design. The jatropha seed cake levels performed equally as well as the inorganic fertilizer treatment in terms of maize dry matter yields at 4 and 8 wace. The maize grain yield was significantly higher ($P<0.05$), thus 954 kg ha^{-1} and 1036 kg ha^{-1} when jatropha seed cake was applied at 767 kg ha^{-1} and 1534 kg ha^{-1} rates respectively. The zero rate had lower grain yield (538 kg ha^{-1}). The interaction between the jatropha seed cake rate and inorganic N rate was not significant ($P>0.05$). The results from this study suggest that smallholder farmers can apply jatropha seed cake at a rate of 767 kg ha^{-1} at planting and 25 kg ha^{-1} inorganic N can be used as a top dressing fertilizer in maize production in Zimbabwe.

Key words: Jatropha, seed cake, fertilizer, grain yield

Introduction

Maize is the staple crop of Zimbabwe accounting for 60 % of the cropped area. (Nyamangara, *et al.*, 2003)**.** Zimbabwe was often referred to as a success story in terms of food security and this status is probably because of expanded maize production as yield per unit area is characteristically low, averaging less than 700 kg ha^{-1} nationally in the smallholder sector (Agricultural Sector of Zimbabwe Bulletin, 2000).

Soil fertility has been cited by many researchers (Grant, 1970, Grant, 1981, Mashiringwani, 1983, Mukurumbira and Dhliwayo, 1996, Nyamangara, 2001) as the major constraint to maize production. Most smallholder farmers grow maize on sandy soils derived from granite

(Nyamapfeni, 1991). These soils are characterized by deficiencies of N, P, K and S, relatively high acidity (Grant, 1981), low soil organic matter (often below 0.3 %) (Campbell, Bradley, and Carter, 1994) and low water holding capacity (Grant, 1981; Vogel, 1992). Increased continuous mining of the soil by repeated crop production with little fertilizer or organic matter input has further depleted the soil nutrients. However, most of these production constraints can be alleviated by the application of high quality organic amendments.

Some of the soil ameliorants used by farmers include inorganic fertilizers, cattle manure, and miombo leaf litter, of which miombo leaf litter tends to be of very low quality (1.2 % nitrogen (N)) with limited contribution to maize yields (Snapp, Mafongoya and Waddington, 1998). Manure is of particular importance on sandy soils because it can improve both physical and chemical properties of the soil. The chemical composition of manure varies greatly from place to place.

Quantities of cattle manure available to farmers in Zimbabwe are however limited because of low livestock numbers per household (Nzuma, Murwira and Mpepereki, 1997) and hence use of manure is not widespread. The use of inorganic fertilizers is also severely limited because of unavailability and the inhibitive cost. Use of combinations of organic and inorganic fertilizers has thus become imperative (Hikwa *et al.,*1998) to increase yield levels, but this entails the need to find alternative supplementary sources of nutrients for soil fertility management under maize production. *Jatropha curcas* L. (jatropha) seed cake (also known as jatropha press cake) an organic source of nutrients, has shown a lot of promise in other countries. Gubitz (1998) reported maize yield increase of up to 179 % compared to a commercial fertilizer. Some of the uses of the seed cake that have been suggested include biogas production and fodder. The seed cake contains about 50 % protein but cursin, insoluble in the oil, remains in the seed cake rendering it toxic to animals (Wegmershaus and Oliver, 1980). The cake can therefore not be used as a stock feed without treatment; it can however alternatively be used as an organic fertilizer.

The Zimbabwe Government has embarked on a National Bio diesel Production Programme. The species that is being promoted is jatropha. It is expected that, by 2010, 10 % of the annual national diesel requirement will come from jatropha oil. This can be realized if at least 100,000ha of land would be put under jatropha. Most of the jatropha will be grown in the smallholder sector (Mushaka *et al.,* 2005).

The issue of biofuel production has aroused fears that crops will be grown especially for oil production at the expense of food crop production. This has been worsened by the vagaries of climate change which have contributed to the food shortages that have been experienced the world over. From a development point of view, the issue of jatropha production can be viewed from two angles namely biofuel production and the opportunity to improve food crop productivity through the use of jatropha seed cake in soil fertility improvement programmes. The amounts of seed cake residues anticipated from the Zimbabwe programme, will increase significantly in the future as the programme gains momentum. Working with a conservative yield level of 3 t per hectare, 300 000 t of Jatropha cake residue can be produced per year when 100 000ha land has been put to jatropha use. It is therefore important that appropriate ways of disposing the cake are developed. Using the jatropha seed cake as a fertilizer could result in increased maize yields thus, positively impacting on food security. This study explored the possibility of using jatropha seed cake waste as an organic fertilizer to mitigate shortages of fertilizing material and to improve maize yields per unit area in the smallholder-farming sector of Zimbabwe.

Materials and Methods

Experimental Site

The experiment was conducted at Henderson Research Station (30^o 38’ East and at 17^o 35’ South) in Mazowe, about 30km East of Harare, Zimbabwe. The site lies in the Agro ecological Natural Region (NR) IIb, which is an area of high agricultural potential in Zimbabwe. The average annual rainfall is 700 - 1000mm (Vincent and Thomas 1961) and it is mostly restricted to the summer season (November – April). The soil at the experimental site was medium grained sandy, with a pH of 4.0 ($CaCl_2$). The average annual temperature of the site is 28 ^oC. The site had been fallow for one year.

Experimental design and treatments

A factorial combination of treatments arranged in a randomised complete block (RCB) design with three replicates was used. The first factor comprised of the jatropha cake rates which were 0 kg ha^{-1}, 767 and 1534 kg ha^{-1} applied at planting in furrows which were 5 – 10 cm deep. A thin layer of soil about 2cm was applied to cover the cake. The jatropha seed cake rates were based on the amount of nitrogen (N) calculated at 0, 25 and 50 kg ha^{-1} respectively. The control was the extension recommendation inorganic fertilizer rate of 200kg ha^{-1} Compound D (8 % N, 14 % P_2O_5. 7 % K_2O, 6.5 % S), which was applied at planting. The second factor was the inorganic N fertilizer rates of 0, 25 and 50 kg ha^{-1}. The inorganic N fertilizer was applied at 6 weeks after crop emergence as top dressing fertilizer. Ammonium nitrate fertilizer (34.5 N) was used as the source of inorganic nitrogen. A total of 12 treatments were tested in the experiment. The maize variety used in the experiment was SC 513, a white dent early maturing three way hybrid. The variety was chosen because of its tolerance to GLS, which is prevalent in high rainfall areas, and also its tolerance to stress (Seed Co, 2004) as rainfall distribution is sometimes poor in NR IIb. The variety is commonly grown by smallholder farmers.

Source of jatropha seed cake

The jatropha seed cake used in the experiment was sourced from Harare Poly technical college where it is a waste product of oil extraction. A sample of the jatropha seed cake was analysed at the Chemistry and Soils Research Institute in the Department of Agricultural Research and Extension (Harare) in December 2006. The mineral nutrient concentrations for N, phosphorus (P) and potassium (K) were 3.26, 0.504 and 2.25 % respectively (Chemistry and Soils Research Institute analysis report, 2006) (see Table 27.1 for more information). The lignin content of the cake was 13.3 %. The gross plot was 5.4 m x 6 m. The inter row and intra row spacing was 90 cm x 30 cm and the net plot was 1.8 m x 3 m.

Table 27.1: Mineral Nutrient Content of Jatropha Seed Cake

Mineral Nutrient	Content
Nitrogen (%)	3.26
Phosphorus (%)	0.504
Potassium (%)	2.25

Sampling of maize plant parts and grain yield

The above ground maize parts of two plants, from the two boarder rows were cut at ground level at each sampling period i.e. at 4, 8 and 12 weeks after crop emergence (wace). The samples were weighed to determine fresh biomass yield then they were dried at 60^o C for 4 days for dry matter determination. The moisture content of the maize grain was determined and was adjusted to 12.5%. Grain data standardization of was also done.

Management of the experiment

The land was ploughed using a tractor drawn disc plough. Planting was done on the 22^{nd} of December 2006. Hoe weeding was done twice at 2 and 5wace. The maize crop was harvested at physiological maturity. Daily rainfall figures were recorded at the site using a rain gauge.

Data Analysis

The Analysis of Variance (ANOVA) was performed to determine overall treatment effects for the dry matter and grain yield variables. GENSTAT Statistical Package Version 8. ANOVA was used. Maize dry matter yield data at 4wace was transformed using the Box cox method. Mean separation was done using the Least Significance Difference (LSD) to separate treatment means that were significantly different for maize dry matter yield and grain yield parameters. Alpha level 0.05 was used.

Results

Rainfall distribution at Henderson Research Station

The 2005/06 season received 456 mm of rainfall which translates to about 65% of the past 5 year average potential of Mazowe area of 700mm. The rains were spread over the months of November 2006 to March 2007 with less than 100mm being received per month in November, December and March (Figure 27.1). The poor maize yields can be attributed to the poor rainfall distribution, especially the moisture stress experienced during the flowering and grain filling stages.

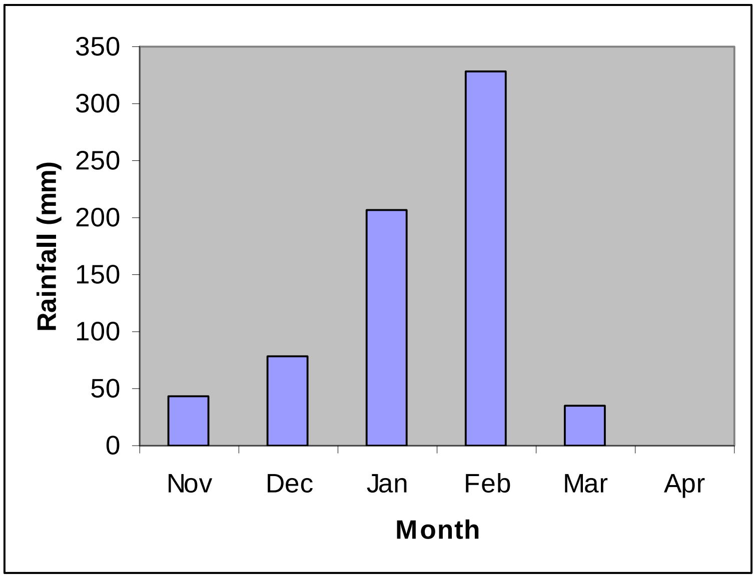

Figure 27.1: Rainfall graph for Henderson Research Station for 2006/2007 Season

Effects of jatropha seed cake on dry matter yield at 4, 8 and 12wace

At 4 wace the jatropha seed cake application rate of 1534 kg ha^{-1} and the extension recommendation inorganic fertilizer treatment had significantly higher ($P<0.05$) maize dry matter yields (339 kg ha^{-1} and 317 kg ha^{-1}) respectively . There was no difference ($P>0.05$) between the lower jatropha seed cake rate of 767kg ha^{-1} and the extension recommendation inorganic fertilizer treatment (Figure 27.2). The zero rate had the lowest yield of (172 kg ha^{-1}). At 8wace a similar trend was noted. The zero rate treatment had a significantly ($P<0.05$) lower yield compared to all the other treatments. The jatropha seed cake rates of 767 kg ha^{-1}, 1534 kg ha^{-1} and the extension recommendation treatments had almost double the maize dry matter yields (all above 2000kg ha^{-1}) with the zero rate having 1180 kg ha^{-1} (Figure 27.2).

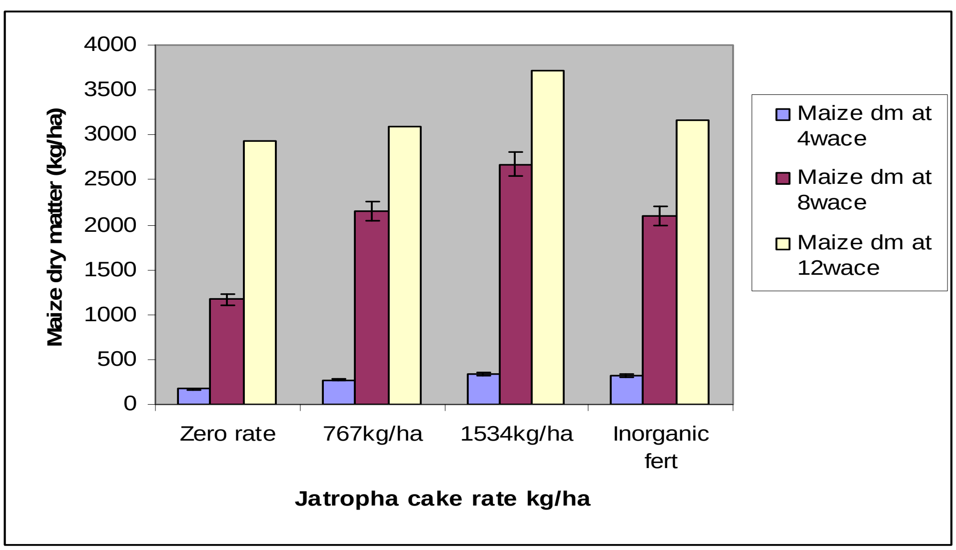

Figure 27.2: Effects of jatropha cake application rate on maize dry matter yield at 4, 8 and 12wace

There were no significant differences (P>0.05) on dry matter yield at 8 and 12wace due to the addition of top dressing inorganic N fertilizer (Figure 27.3).The use of jatropha seed cake and inorganic fertilizer resulted in significantly higher (P<0.05) grain yield. There were however no differences (P>0.05) between the two jatropha cake levels (767kg ha^{-1} and 1534 kg ha^{-1}) and the inorganic fertilizer treatment (Table 27.2). The zero rate had a significantly lower (P<0.05) yield of 538 kg ha^{-1} compared to the jatropha seed cake and inorganic fertilizer treatments. Grain yield increased with the addition of inorganic nitrogen fertilizer from 605kg ha^{-1} to 1033kg ha^{-1} (Table 27.2). There was no significant difference (P>0.05) between the two inorganic nitrogen application level of 25 kg N ha^{-1} and 50 kg N ha^{-1}. The interaction between the jatropha seed cake application level and the inorganic nitrogen fertiliser was not significant (P>0.05) (Table 27.2). These results show that the jatropha seed cake and the inorganic nitrogen acted independently in increasing maize grain yield.

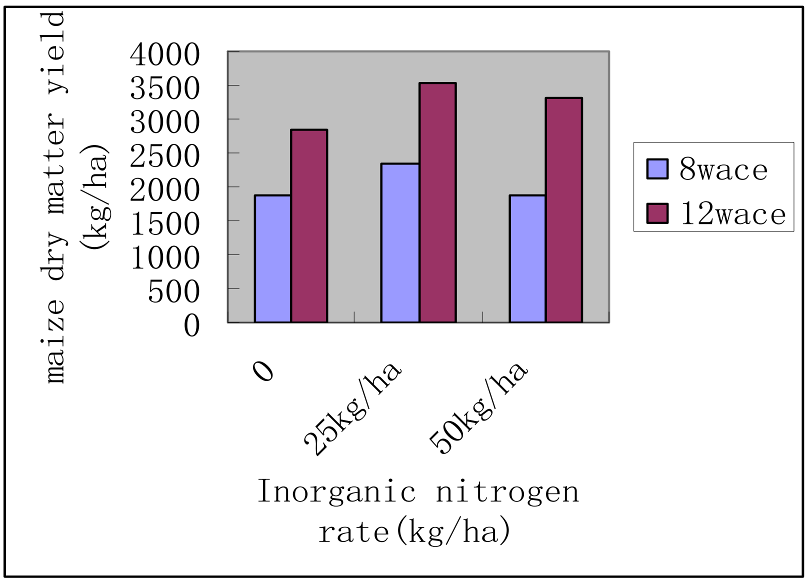

Figure 27.3: Effects of inorganic nitrogen fertilizer on maize dry matter yield at 8 and 12wace

Table 27.2: Effect of Jatropha Cake Application Rate, Inorganic Nitrogen and the Interaction on Maize Grain Yield

Jatropha cake rate	**Inorganic N rate**			**Means**
	0	***25 kg ha^{-1}***	***50 kg ha^{-1}***	
Zero rate	622	653	339	538 [b]
767kg ha^{-1}	621	853	1389	954 [a]
1534kg ha^{-1}	641	1244	1222	1036 [a]
Inorganic fertilizer	536	1139	1182	952 [a]
Means	605[b]	972[a]	1033[a]	
		P Value	LSD	
Effect of jatropha		0.017	319.2	
Effect of Inorganic N		0.009	276.4	
Jatropha X N interaction		0.103	ns	

Discussion

Effect of jatropha seed cake application rate and inorganic fertilizer on maize dry matter yield

Maize dry matter yield responded positively to the application of jatropha seed cake. Use of the jatropha seed cake resulted in higher yield increase probably due to the availability of nitrogen and other nutrients such as potassium and zinc released from the jatropha seed cake. The dry matter accumulation was lower in the zero rate treatment possibly because of the low soil pH. The rapid biomass accumulation by the jatropha cake treatments might be an indication that there is little immobilization of N from the time of application. The jatropha seed cake used in the experiment was a good organic source of nutrients as it had an N content of 3.26% which is greater than 2.5% and 13 % lignin which is less than 15% (Van Lauwe *et al.,* 2002).

Even though there were no differences in dry matter yield between the jatropha cake rates and inorganic fertilizer treatment the rate of accumulation was lower in the fertilizer treatment this was possibly due leaching of N. The high dry matter accumulation in the jatropha treated plots can also be possibly attributed to the release of other nutrients such as potassium and possibly micro nutrients such as zinc by the jatropha seed cake.

The maize plants however showed acute phosphorus deficiency in the control plots and all the jatropha seed cake treatments. This is explained by the low phosphorus content (0.504 %) of the cake. This meant that application of 767 kg ha^{-1} of jatropha seed cake translated to the application of 3.87 kg ha^{-1} of phosphorus. This amount was much lower compared to the amount of phosphorus supplied by the Compound D inorganic fertilizer which amounted to 28 kg ha^{-1} .

Application of top dressing inorganic nitrogen did not significantly affect maize dry matter yield. This was probably due to leaching as the inorganic nitrogen fertilizer was applied in February. About 47% of the seasonal rains were received in the month of February. The low maize dry matter yield achieved by the control plots on the sandy soil site might also be explained by the low pH of the soil which was 4.0

Effect of jatropha seed cake application rate and inorganic fertilizer on maize grain yield

Application of inorganic nitrogen fertilizer as topdressing fertilizer resulted in significantly higher yield grain yields compared with the zero rate. The pH of the soil was low (4.0) and this explains the low grain yield from the zero rate treatment. The lower inorganic nitrogen fertilizer rate (25 kg ha^{-1}) gave comparable grain yield with the higher rate (50 kg ha^{-1}N). The lower grain yield could also be attributed to the poor distribution of rainfall and the premature end of the rain season. The results of this study suggest that farmers can however use a lower rate (25 kg/ha) of inorganic nitrogen when growing maize under similar rainfall and soil conditions.

Effects of jatropha cake application rate on maize grain yield

Maize grain yield responded positively to the application of the jatropha seed cake. Maize grain yields were higher where the jatropha seed cake and the inorganic Compound D fertilizer were applied compared to the zero treatment. The increase in grain yield could be attributed possibly to the nitrogen released by the seed cake and the other nutrients supplied by the cake. The seed cake has about 88 % organic matter content (Agronomy Research Institute, 2002) this probably contributed through improving the physical characteristics of the soil leading to improved water and nutrient holding capacity which probably aided crop growth and grain yield.

Conclusion

Use of jatropha seed cake resulted in high maize dry matter yields. This is of particular importance in the smallholder farming sector where maize stover is used as livestock feed during the dry season and bedding for livestock among other uses. The livestock and crop production systems are closely linked and hence farmers will benefit from the use of jatropha seed cake.

The jatropha application rate of 767 kg/ha gave higher maize yields. It performed comparably with the inorganic fertilizer treatment. This suggests that the use of a low jatropha seed cake rate can result in improved maize yields that are comparable with the use of inorganic fertilizer in the sandy soils in the smallholder sector. Currently in Zimbabwe the national jatropha programme is still in its infancy and hence there is very little jatropha seed cake. The smallholder farmers can utilize the limited quantities available for maize production. Jatropha seed cake can be used as a strategy to improve the soil fertility status of the granitic sandy soils of Zimbabwe and specifically the nitrogen levels.

The onus is now on the Zimbabwe national jatropha programme to ensure that the hectarage under jatropha is increased so that more farmers can benefit from the jatropha seed cake in the near future. The growing of jatropha and use of jatropha seed cake for soil fertility improvement will result in the improvement of maize grain yields, hence the satisfaction of both food and bio energy needs. There is need to increase maize grain yield on the existing hectarage. Productivity gains from increased yields per unit area will eventually meet and possibly exceed the growing demand for food. Besides providing jatropha seed cake the jatropha plants will act also act as carbon sinks impacting positively on the effects of global warming.

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28. Bioenergy and Development in sub-Saharan Africa: Are the Policies Conducive?

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Abstract

This paper analyses different national, regional and international biofuels policies and strategies to assess how these policies promote or undermine the development of biofuels industry in Africa. The policies and strategies reviewed include policies of selected countries, the EU, COMESA, East African Community, SADC, AU, USA, ECOWAS, and those for the UN agencies (UNIDO and UNCTAD focusing on trade and investment potential in biofuels, and the Kyoto Protocol. The main findings from this review are that although sub-Saharan Africa (SSA) in general has a huge comparative advantage in producing energy crops without disturbing the traditional farming systems and the ecosystem, few countries have included strategies in their energy policies or national development frameworks. There are also sharp differences in political commitment to biofuels industry development by individual countries with some countries making technological advances (e.g., South Africa) while others lag behind. Some countries in SSA have embarked on small-scale production of energy crops without accompanying investment in infrastructure for processing, storage, distribution and marketing of biofuels products. While the EU and USA commit huge financial resources for research and development and provide tax-incentives for promoting biofuels, there is no government support to the biofuels sector in SSA. Further, the regional economic groupings in Africa such as SADC, COMESA, ECOWAS and the AU do not have a coherent regional policy agenda for developing the biofuels sector with specific targets unlike in developed countries. With the growing interest in biofuels worldwide, there is need for national governments in SSA to develop mechanisms for harnessing the potential of the fast growing industry and benefit from the growing international trade in biofuels while at the same time protect the environment and rural communities from being disadvantaged by large-scale cultivation of energy crops for biofuel production.

Key words: biofuels, energy policies, sub-Saharan Africa

Introduction

Although energy continues to be the pivot of economic and social development of all countries around the world, increased consumption of fossil fuels has been the subject of on-going debate centred especially around the destructive effects on climate change of increased use, leading to greenhouse gas emissions and their devastating effect on global warming and climate change (UN-Energy, 2007). Bioenergy resources have traditionally been used by rural households for cooking and heating for centuries. Today, more than two billion of the world's poorest people depend on coal and biomass such as wood, charcoal, crop residues and dung to meet their daily energy needs (IEA, 2002). Estimates indicate that between 80 and 90 percent of the people in sub-Saharan African countries (SSA) depend on biomass fuels and fuelwood accounts for more than 75 percent of the household energy balance (WHO, 2002). For many developing countries, biomass energy will remain the primary and affordable source of energy for the unforeseeable future by the majority of rural people.

Since the last two decades, biofuels[i] especially liquid biofuels have risen to the top policy agenda in the United States of America, European Union, Canada and Asia. This renewed interest in biofuels mainly arises from the quest for increasing national energy sovereignty to turn the tide of increasing dependence on Middle East oil, environmental concerns from use of fossil fuels in the transportation sector and soaring world energy prices (OECD/FAO, 2007). In particular, the rapid economic growth in India and China is also putting enormous pressure on the price of oil due to the huge demand for oil required to run these economies. All these factors have stimulated great interest in exploring the role that energy crops should play in diversifying energy sources.

Today, substantial amounts of oilseed rape and soyabean oils are converted into biodiesel in the EU, the US and Canada (Takavarasha *et al.,* 2005). Brazil was the first country to start a major ethanol production program followed by the US. Recently in 2003, the EU member states have set a target of incorporating 5.75 percent of biofuels in the total of fuels used for transportation by 2010 (Hodson, 2006). Brazil has set mandatory targets that all diesel used in the transportation sector contains 2 percent biodiesel by 2008 and 5 percent by 2013. America has an aggressive scheme to replace 15 percent of the petrol-powered cars with “green-fuel” vehicles with the aim of reducing petrol consumption by 20 percent by the year 2020. In 2006, 20 percent of the whole maize crop across the US went to ethanol production meeting two percent of its automobile fuel consumption.

In Africa, Malawi is among the few countries that started producing bioethanol from sugarcane molasses since the early 1980s, where ethanol produced from sugarcane molasses is blended with imported petrol, presently at 10 percent, in order to reduce the volume of imported petrol for transportation (between 80 and 90 million litres of petrol is imported every year). In October 2007, Malawi imported an ethanol-propelled car from Brazil and has launched a pilot program to modify the engines of some vehicles to run on ethanol or a mixture of ethanol and petrol.

Developments in the biofuel sector by industrialized countries offer both promises and challenges for developing countries in sub-Saharan Africa. While sceptics argue that biofuel production will threaten food supplies for the poor, others argue that if well managed, biofuels can be produced profitably and stimulate rural economic growth in developing countries. According to von Braun and Pachauri (2006), biofuel production can create demand for energy crops such as sugarcane, soybeans, rapeseed and oil palm that are grown by rural farmers. In addition, farmers can increase their incomes by growing energy crops such as *Jatropha curcas* on degraded or marginal land not suitable for food production. It is also argued that, as technology advances, a modern biofuels industry could also provide developing country farmers with additional income from straw, grass, crop residues, stalks and leaves that can be converted into biogas, ethanol or electricity.

Worldwide, the use of biomass in the energy supply will invariably increase in the coming decades. The recent UNDP report predicts that the global production of biofuels doubled over the past five years and is predicted to double again in the next four years (UN-Eneegry, 2007).

According to OECD/FAO (2007), demand for biofuels will grow by 170 percent in the next three years and will contribute 25 percent of the world energy needs in the next 15 to 20 years. Due to vast natural endowment – climate, arable land and water resources - investors have already started purchasing land in Africa for growing biofuels feedstocks, and some are putting up infrastructure for the processing of biofuels in Africa (e.g., SASOL in South Africa). The large-scale planting of energy crops requires that new areas be opened up for growing energy crops. This will offer opportunities for farmers, producers, processors and investors involved in this industry. We examine the implications of different policies for the biofuels industry in Africa.

Objectives of the study

This paper explores the extent to which the national policy frameworks for sub-Saharan African (SSA) countries such as poverty reduction strategies (PRSPs) and national energy policies incorporate strategies for mainstreaming or supporting the development of the biofuel sector. Specifically, the study aims at addressing the following questions:

1. What do the national policies state with regard to bioenergy or biomass energy development?
2. What are the notable gaps in the policies across countries with regard to bioenergy and energy crops development?
3. What is government's commitment in implementing the policies?
4. Have governments allocated resources for implementation?

Addressing these questions is vital for a number of reasons. First, this analysis helps to assess the extent to which the national policies provide a supportive legislative framework for the development of the biofuel sector while safeguarding the livelihood systems of the vulnerable people. This will ensure that the poor are not further impoverished by converting arable land for biofuels production at the expense of food production, or squeezing the profits from smallholder farmers involved in biofuel production to the advantage of the private sector.

Second, biofuels offer a great opportunity for diversifying energy sources and livelihood systems of rural communities through employment creation in the bioenergy industry, production and marketing of biofuel products. This analysis helps to assess whether there are clear government regulations and incentives for the development of sustainable biofuels industry.

Third, this analysis tries to assess whether there are appropriate policies and technologies for the production of non-food feedstock for biofuel production as a way to safeguard the potential dangers of biofuel production on the environment. Lastly, the study identifies some challenges in the implementation of the policies and design measures to mitigate the adverse effects of implementing faulty policies.

Biofuel initiatives in some African Countries

Many countries in sub-Saharan Africa have started a number of initiatives aimed at reducing the volume of imported crude oil since the majority of the countries are land locked and do not have oil reserves. For example, Malawi started producing ethanol in 1982[ii] which is blended with petrol in order to reduce the fuel import bill where between 80 and 90 million litres of petrol is imported every year. Other countries such as Kenya, Zimbabwe and Sudan started programs to blend ethanol with petrol in the 1980s to reduce the fuel import bill. Sudan and Kenya stopped producing ethanol, but Kenya has since revived its ethanol production. Zimbabwe continued producing ethanol, but not the blending of ethanol with petrol. Much of the ethanol produced by these countries is exported to other countries as alcohol. A number of countries in Africa such as Mauritius, Ghana and recently Egypt, Zambia, Nigeria, South Africa, Mozambique, Mali, Tanzania and Ethiopia have started ethanol production from sugarcane molasses after Malawi had gone into full production in the 1970s.

In Uganda and Mali, the public sector is directly involved in producing biofuels; its primary role is to create an environment conducive for the development of the sector such as policies and regulations, incentives, extension advice, information and market infrastructure. In many African countries such as South Africa, Malawi, Tanzania and Zambia, biofuels production has been the domain of the private sector mainly focussing on ethanol and biogas production.

For ethanol, private firms operating sugar mills play a major role in the development of the biofuel sector. For example in Malawi, two private companies namely, Ethanol Company of Malawi and Press Cane in the Central and Southern Regions of Malawi are involved in ethanol production. The Ethanol Company of Malawi received government support for developing an ethanol plant in 1980s. In both companies, large sugar plantations owned by the Illovo Group provide the raw materials (molasses) which is further processed into ethanol. However, some of the molasses is provided by smallholder farmers who grow sugarcane under out-grower schemes. In many countries, farmers are involved in the sector as the main providers of raw materials throughout-grower schemes. For example, most of the sugarcane in Kenya is grown under out-grower schemes. This arrangement helps the local communities to not only be involved in gainful employment, but also participate in economic activities of their countries.

In Mali, *Jatropha* is grown by local communities supported by the Mali–Folke Centre, which has been working with local communities in promoting Jatropha as a raw material for biodiesel production (UN-Energy, 2007). Communities living within a 20km radius from the Centre benefit from biodiesel production activities. In addition, these communities are also employed to run the power plants for electricity generation thereby creating employment. In the village of Tiecourabongoe, an energy service centre has been established focusing on Jatropha. Due to the success of the project, the Mali-Folke Centre has embarked on a large-scale 15 years rural electrification project in Southern Mali produced from Jatropha oil. Under the project, 1,000 hectares of Jatropha plantation will be established to provide fuel for a 300kw power plant. This is expected to benefit more than 10,000 residents, which is expected to transform the lives of rural communities in Southern Mali.

In Tanzania, there are a few small scale on going bioenergy projects such as the Solid Bioenergy, a SADC Program for Biomass Energy Conservation (PROBEC). These programs aim at improving the supply and use of solid bioenergy for improved rural livelihood. On biofuels, there exist several initiatives from the national to the local levels with the objective of developing policies, regulations and programmes aiming at ensuring sustainable development of liquid bioenergy in Tanzania. The government through a biofuels Task Force is working on the preparations of policies, regulations for creating enabling environment for stakeholders to participate in the development of biofuels. Local institutions such as Kakute currently support small farmers to grow Jatropha and sell its oil for soap production. TaTEDO is implementing a number of activities which include awareness creation at all levels, supporting small farmers to grow and process Jatropha and sunflower to provide oil for powering multifunctional platforms and sell extra to private companies buyers. TaTEDO will be undertaking such activities in more than 120 villages in the next five years starting January 2008. There are also other biofuels initiatives in Zambia, Zimbabwe, Senegal, Mozambique and South Africa aimed at promoting biofuels and developing appropriate technologies for the rural communities.

Synergies and trade-offs between bio-energy and agricultural production systems

A number of controversial issues have been discussed in different fora questioning whether the growing interest in biofuels will provide opportunities for improving rural livelihoods or will exacerbate poverty. From the literature, both positive and negative relationships among the biofuels industry, agriculture and food security have been documented. According to Woods (2006), large scale and mechanized farms will not be appropriate for growing energy crops in many developing countries. As the biofuels sector develops, smallholder farmers in the SSA are likely to play a critical role in the production of the bioenergy crops. Thus, small-scale production and processing of energy crops to produce biofuels would help to add value to locally produced crops by rural communities, thereby enhancing their incomes.

With improved technologies, scientists and investors are developing more energy efficient crops as well as efficient methods of extracting oil from the energy crops. For example, Monsanto, a private company, has developed a variety of corn that yields more ethanol per hectare (Lanely, 2006). A number of technologies are being developed to extract ethanol and biogas from non-food feedstock such as crop residues, straw, grass and leaves. The breakthrough in research and technology that will make it possible to use non-food feedstock in biofuels production will help to diffuse the fears of food insecurity associated with large scale production of energy crops for biofuels production. It must be pointed out though that it will take a long time for such advanced technologies to mature and diffuse to Africa considering their high capital cost.

One of the benefits of the biofuel sector is its potential to produce biodiesel to power generators for electricity generation that can also be used to run hammer mills. As Woods (2006) observes, many developing countries may be able to leapfrog first generation bioenergy technologies, particularly in the production of bioelectricity and liquid fuels for transportation. In fact, Mali and Tanzania have championed the production of electricity using Jatropha involving rural communities. Such initiatives must be encouraged and supported to stimulate rural economic development.

Although the biofuel sector may have several advantages for rural communities in sub-Saharan Africa, there are a number of challenges. The major concern regards the potential competition between biomass systems for biofuels production and the use of biomass resources for animal feed, bedding, fertilizer and construction materials (UN-Energy, 2007). In addition, the production of energy crops might be so attractive in terms of price ratios and income that may induce the diversion of resources away from food crop production for biofuels thereby threatening food security (SADC, 2005).

Further, there are controversies surrounding the impact of biofuels production on food security, environment, land and water use. For example, other studies have shown that the SADC region has the potential to produce sufficient raw materials needed for biofuels without adversely affecting the ecosystem, food security and traditional farming system (SADC, 2005). In terms of water use, studies in other parts of the world have shown that production of energy crops for biofuel production can have substantial impact on water demand especially if irrigation is used for their production (e.g., Fraiture, Giordano and Yongsong, undated).

In terms of incomes and food security, biofuels development may have positive benefits on ensuring household food security through increased incomes and markets for energy crops. In fact, many countries have expressed growing interest in Jatropha as feedstock for biodiesel production. Since Jatropha can grow relatively well in marginal areas compared to other traditional crops, it may help to reclaim degraded land and protecting the soil from erosion. In addition, Jatropha production may be inter-planted with other annual crops without changing the traditional agricultural production system. However, since Jatropha typically grows in the wild and has traditionally been used for making soaps and candles, there is need for research into its agronomy as a cash crop.

With its high starch content, cassava also holds promise as a feedstock for ethanol production. From an economic development standpoint, cassava could be a desirable feedstock because it is already grown in developing countries and can be cultivated with comparatively low input and labour requirements compared to those required for growing maize. Depending on feedstocks and technologies used, biofuels production may create food supply shortage. It is for this reason that national governments need to undertake proper and systematic, country-specific research to ascertain the viability and economic feasibility of biofuels in their setting.

Regulatory and institutional frameworks for biofuels development in sub-Saharan Africa

The sustainable development of a viable biofuels industry requires a strong, supportive policy, and a firm legal, regulatory and institutional framework to ensure that measures are put in place to harness the contribution of the sector to rural livelihood. This section analyses the policy frameworks relevant for the development of the bio-fuels sector in the Sub Saharan countries. We present an overview of the country policy statements to identify specific policy thrusts for the development of the biofuel sector.

National development policy frameworks and bioenergy sector

The study examined the major available policy frameworks especially the Poverty Reduction Strategy Papers (PRSP) for 17 sub-Saharan Africa (SSA) countries. Our aim was to determine the extent to which bioenergy and biofuel issues are addressed. For the PRSPs reviewed, the main thrust is to reduce poverty through different interventions including increasing access to affordable energy sources for domestic and industrial uses. The biofuels sector generally fits within the national policy frameworks.

Many PRSPs highlight the connections between energy and reduction in income poverty, while a few (e.g., South Africa) mention the linkage between energy and food security. Takada and Charles (2007) observe that most PRSPs have stressed the expansion of electricity supply as a principal strategy for meeting energy needs, while only eleven PRSPs have explored the potential for decentralized and renewable energy options for meeting energy needs. These PRSPs are for countries such as: Burkina Faso, Cameroon, Ghana, Madagascar, Malawi, Mali, Mozambique, Nigeria, Sierra Leone, Senegal and Zambia.

From the analysis, a number of issues emerge. Despite the fact that the biofuel sector is becoming an increasingly important sector in national and international economic development, the biofuel issues are not elaborately discussed in most national policy frameworks. As shown in Appendix 1, out of the 17 PRSPs reviewed, only the PRSP for Ghana contains specific strategies for biogas development[iii]. This is consistent with the findings of Takada and Charles (2007) who also found that virtually all African PRSPs recognize the role of energy in macroeconomic growth and its importance as a factor of production, but do not have specific strategies for the biofuels sector.

One possible explanation why biofuels are not adequately featured in the PRSPs could be that the momentum on biofuels has just peaked during the last two or so years. The growing impetus for biofuels is likely to instigate changes to the existing national policy frameworks to support the development of a vibrant biofuels sector. In fact, some countries have developed specific biofuels strategies or incorporating biofuels in their national energy policies as discussed below.

National energy policies /strategies and the biofuels sector development

This study reviewed seven national energy policies and two specific biofuels strategies from sub-Saharan countries[iv]. Most of the policies were developed during the last five years and many countries are still in the process of developing their policies. Almost all energy policies have policy statements on general biofuels development without concrete strategies and institutional framework for implementation.

For many energy policies, biofuels are discussed within a group of renewable energy sources. For example, although ethanol has been produced and blended with petrol in Malawi since 1982, its national energy policy approved in 2003 discusses ethanol among liquid fuels. In the policy, ethanol blending is mandatory. The new energy law yet to be passed by parliament will make petrol-ethanol blending mandatory. The recent launch of ethanol-powered vehicles in October 2007 shows that the Government of Malawi is committed to finding alternative and cheap sources of fuel to replace imported fossil fuels.

In the case of Mozambique, although the Government has not finalized the national energy policy document, it has already adopted preliminary regulations to foster large-scale production of bio-fuels for domestic consumption and exports, including the gradual introduction of blending of petrol (gasoline) with ethanol and bio-diesel with fossil diesel, initially, at 5 – 10 percent[v].

Some countries such as South Africa and Ghana have developed specific biofuels strategies with even more specific targets. For example, the Government of Ghana has set a target of substituting 20 percent of national gas and oil consumption with biodiesel by 2015, and 30 percent of national kerosene consumption is to be replaced with Jatropha oil by 2015. The policy also aims at improving the efficiency of production technologies and techniques of biodiesel in order to reduce costs. The proposed biofuels strategy for South Africa aims to achieve a market penetration of 4.5 percent, of liquid road transport fuels (petrol and diesel) in South Africa by 2013. In general, with the growing interest in biofuels worldwide, this study envisages a major reorientation of energy policies to include specific strategies in order to harness the economic opportunities of biofuels development while at the same time protect the environment and rural communities from exploitation by large companies.

Trade and investment policy incentives for biofuels sector development in Africa

As stated earlier, the development of national policies on biofuels has largely been driven by three major policy goals. These are the motivation to reduce trade imbalances through reduction in oil import bills and increase export earnings, increase national energy security, and support rural development through increased bio-energy crop production and processing. However, a fourth driver is the need to mitigate environment problems related to the use of fossil fuels. There are a lot of trade benefits in promoting the use of biofuels. Consequently, interventions in the form of public policy incentives became inevitable. Such interventions would make biofuels production competitive during the early stages of its market development.

Trade and investment policies and their implications for biofuels sector development in sub-Saharan Africa

Since the biofuels sector is relatively new, most trade policies and discussions focus on general renewable energy and may not be specific to biofuels. However, the fact that biofuels may not have been the centre stage in the current trade negotiations does not imply that biofuel trade does not offer potential benefits for the economies of SSA. There are six areas in which trade opportunities for the biofuels sector exist. These are:

1. cross border movement of planting seed for energy crops;
2. trade in feedstock to guarantee year round processing in countries with bigger capacity;
3. movement of biofuels to countries with bigger processing capacity;
4. trade in finished product biodiesel and ethanol with high consumption countries;
5. trade in finished and semi-finished bio-diesel products, and
6. Trade in machinery and processing equipment.

According to Dufey (2006), the use of policy tools such as national targets for blending of biofuels with standard fuels, tax benefits, subsidies and loan guarantees to encourage greater production and consumption have been advocated in western countries. This has led to a breakthrough in biofuel research and technology development in those countries. In this respect, Dufey reports that as a response to the rising oil prices in the 1970s, Brazil started a programme to promote biofuels in 1975 aimed at producing ethanol for locomotives to replace petrol. A number of policy measures were introduced. These include (a) production quotas, (b) fixed purchase price for bioethanol, (c) control of domestic bioethanol sales and distribution by a monopolistic public agent, (d) subsidies to bioethanol blend petrol producers, (e) tax incentives to car owners using bioethanol blend with petrol, and (f) soft loans to implement the necessary technical changes for vehicles.

A review of the National Trade Policy documents and analyses from a few African countries shows that African countries have trade and investment policy frameworks to promote or facilitate domestic and foreign investments in various sectors of their countries. Analysis of trade and export promotion policy frameworks of some countries such as Ghana, Tanzania, Malawi and Uganda show that the common policy instruments used to promote trade and investment include: (a) tariff structures such as taxes and duty draw back schemes, (b) non-tariff measures such as quotas and import licensing, (c) trade defence mechanisms such as subsidies and anti-dumping, (d) trade promotion instruments such as export processing zones, and (e) international trade instruments namely bilateral trade agreements.

Of interest here is the question of the extent to which the national trade and investment policies in the SSA region match those of the Brazilian government as reported by Dufey (2006). A simple comparative analysis of the SSA and Brazilian policy frameworks shows one marked difference, that is, the former does not focus on the biofuel sector but other sectors of the national economy whereas the latter is directly focused on development of the biofuels sector. This, therefore, implies that all that is needed is for the SSA countries to extend their current national trade and investment incentives to the biofuels sector. For instance, the Malawi National Export Strategy outlines the five areas of national focus for the export sector promotion (GOM, 2005). These include: the development of an integrated domestic cotton-textiles garments value chain, tourism, agro-processing, services and handcrafts. Apparently, the biofuel sector value chain development is left out despite having an economic and social turn around potential for Malawi. The situation is not different in other SSA countries.

WTO rules and the development of the biofuels sector in Sub-Saharan Africa

We analyse how the biofuels sector fits into the WTO regulatory framework. Literature on trade and biofuels shows that currently, the World Trade Organization (WTO) does not have a specific position on biofuels (Janssen *et al.,* 2007). This is so because energy trade has not been a focus of WTO law and policy. Until recently, a number of key players in energy markets, particularly petroleum, such as Saudi Arabia were not WTO members (International Policy Centre (IPC, 2006).

The absence of a clear WTO position on biofuels trade issues has provided room for different trade analysts and stakeholders to speculate or suggest how the prevailing WTO rules could apply to trade in the sector. According to the IPC (2006), what complicates the international trade policy situation on biofuels is their unusual make-up, that is, they are fuel produced through the transformation of agricultural feedstocks. The complication comes in because the WTO rules were written at a time when biofuels issues were not prominent as they are now.

It is further argued that within the emerging biofuels trade context, three crucial sets of issues concerning WTO rules may affect the production and exporting biofuels. These issues include: (i) biofuels classification within the context of the WTO harmonized system and WTO member obligations, (ii) how subsidies to promote the production or consumption of biofuels fit in the context of WTO rules, and (iii) consistency of domestic regulations and standards with WTO rules on international trade.

Subsidies and biofuels development in sub-Saharan Africa

The questions of how subsidies to promote the production or consumption of biofuels should be considered from the perspective of existing or any planned WTO rules. In addition, how possible "cross-subsidization" should be evaluated. As Peskett *et al.,* (2007) observe, the production of biofuels for domestic use and exports is dominated by a few countries. The USA and Brazil are the largest producers of bioethanol by a large margin, whereas the EU produces almost 95 percent of the world's biodiesel (European Union, 2006).

The concentration of biofuels production and consumption in these countries and regions is, however, not without public sector support. In particular, the biofuels market has been pervasively shaped in all the major producer nations by a variety of government interventions. Subsidization of biofuels has a basis within the WTO framework. Subsidization can have multiple purposes and these purposes may vary in their consistency with the underlying norms of world trade law. For environmental or energy security reasons, the government may subsidize consumers so as to provide them with an incentive to switch from conventional fuel to biofuels (in whole or part) by compensating, or more than compensating, for the added cost. Unlike in developed countries, most developing country governments do not have the economic resources to provide subsidies and other measures to support the development of biofuels sector.

However, the government still has a role to provide indirect subsidies in the form of research and development that can lead to more efficient technologies for the production of biofuels. This kind of subsidy affects the relative competitive positions of domestic versus foreign producers, although developed countries have a competitive advantage over developing countries due to financial and technological constraints facing most African countries. Most developed countries subsidize producers of biofuels which is not the most cost-efficient way of providing incentives for consumers to switch from fossil fuels to biofuels. Of course, subsidies are sometimes justified, as a policy matter, on "infant industry" grounds.

Quality control, standards and certification and bioenergy sector development in sub-Saharan Africa

Related to the issue of biofuel classification is the quality control, standards and certification processes. Generally speaking, international standards promulgated by domestic or European standards bodies or authorities exist, for example ISO standards in relation to testing of certain characteristics of the biofuels. However, given the state of art in biofuel production in Africa, such international standards are difficult to meet in order to penetrate international markets. However, some African countries do export sugarcane-based ethanol in the form of alcohol.

There is a potential for the development of trade in biofuels, particularly because countries with the greatest potential demand for biofuels do not have conditions that would enable them produce biofuels most easily and cheaply. Thus, the increased demand for transportation energy in developed countries and their inability to meet this demand domestically will increase the likelihood of trade in biofuels; this will involve the Africa region with its favourable conditions for producing energy crops cheaply. However, the main driver of regional biofuels development will be to satisfy the regional demand, given that African biofuels cannot be expected to penetrate international markets in the next 10 to more years. In Africa, biofuels have not been standardized as a recognized fuel or fuel blend, neither have national standards been developed. It is for this reason that this study urges RECs and the AU to facilitate the development of regional standards and certification schemes to facilitate trade within the region while efforts are made to advance their production technologies to meet the international standards. Currently, low levels of production, trade barriers such as tariffs and subsidies, and a lack of international standards limit the international trade of biofuels (Lanley, 2006).

Challenges and opportunities for biofuels development in sub-Saharan Africa

The global expansion of biofuels production will have serious ramifications for Africa, which has large land mass and favourable climate for growing energy crops. However, there is need for proper mechanisms to regulate the sector to ensure that biofuels are not given too much priority at the expense of other important values for nature, environment and society[vii]. Of particular concern is the competition for land, water, and the displacement of land used for the cultivation of food and other crops.

With the exception of South Africa, most polices are formulated without analysis of the implications of embarking on the biofuels program. Most policies reviewed have not spelt out strategies to stimulate the demand for biofuels, develop biofuels infrastructure, expand feedstock supplies, develop local and regional markets for biofuels, and increased investment in research and technology development. In countries such as Nigeria and Uganda, although the energy policy defines the role of Government as that of facilitating development, providing stimulus for private investment and initiatives, and monitoring and co-ordination of the sector activities, the government and public universities are still the key players in the energy sector. This contrasts with South Africa, Tanzania, Zambia and Malawi where the private sector plays a pivotal role for the development of the biofuels sector. However, there is still need to establish an authority charged with the responsibility of coordinating biofuels research and development activities.

Because SSA countries have clear comparative advantages in the production of biofuels, they should not only consider incorporating the sector in their national trade and investment policy frameworks but also include it in the current and on-going international trade negotiations. The trade reform efforts will have powerful effects on biofuels expansion. There are concerns that the rapid growth of the first generation liquid biofuels production will raise agricultural commodity prices, and this will have negative economic and social effects particularly on the poor who spend a large share of their income on food. In addition, the current structure of agricultural markets means that most profits go to the wealthier households or foreign investors at the expense of the poor (UN-Energy, 2007).

It has also been argued that despite the attempts to link the biofuels sector to the regional and international markets, not all countries will take advantage of these market opportunities. In some countries, the production of biofuels is concentrated in remote rural areas. As such, when fossil fuel prices increase due to high transportation costs or changes in world oil prices, bioenergy systems may help such countries to become self-reliant in energy by depending on locally produced biofuels. Nevertheless, efforts should be devoted to improving access to international biofuels markets in order to enhance the incomes and welfare of both producers and consumers in Africa.

Howse *et al.* (2007) argue that even though some developing countries may have a comparative advantage in the production of biofuels or biofuel feedstock, potential trade may be stifled by an overly exclusive focus on domestic production. Under these circumstances, biofuels will continue to be produced from low-yielding feedstock. For example, it known that the production of ethanol from sugarcane is significantly more energy efficient and environmentally sustainable than using maize (corn) as feedstock for ethanol production. Rapeseed, which is one of the best yielding temperate crops for oil production is inferior to either palm oil or Jatropha grown in the tropical regions in terms of yield of oil per hectare. However, these concerns may not be justified considering that investment in biofuel crops won't be done without clear investment analyses. The investors with the support of national investment promotion agencies in SSA are likely to undertake thorough analyses of costs and benefits of investing in any of the energy efficient biofuel crops.

Trade and investment Challenges in sub-Saharan Africa

The common challenges across the SSA countries with regard to trade and investment promotion include inadequate national capacities to apply the available instruments. In some cases, the prevailing policy and regulatory instruments are still not quite conducive to both domestic and international investments in a number of sectors including the biofuels sector. In this regard, Bajracharya and Flatters (1999) reports that in Ghana, there are serious operational challenges regarding the duty drawback system since some producers report that drawback payments are extremely slow to be processed and in many cases, almost impossible to obtain. The minimum time required to process a claim was reported to be three to four months; but the norm is much longer, and many claims are never realized. Not only are procedures slow and cumbersome; they also require that claimants relinquish their sole copies of official import documents, creating serious difficulties for subsequent company recordkeeping.

The challenge of red tape, bureaucratic procedures and weak institutions for investment is not restricted to Ghana alone. The Tanzanian National Trade Policy (2003) and the Malawi National Export Strategy both openly acknowledge the existing challenges that discourage foreign direct investment (FDI) and domestic investment (GOM, 2005). These include tax and incentive structures, the slow process for processing of incentives, and inefficiencies of statutory institutions amongst others. In the same vein, Morrissey, Rudaherenwa and Moller (2003) observe that while a number of incentives have been put in place in Uganda under which import duties on certain raw materials may be refunded under VAT and a duty drawback scheme, the refund mechanism in these schemes have attracted criticisms on grounds of inefficiency. This snapshot of SSA region trade and investment challenges has serious implications for the biofuels industry, which is at the infancy stage in many countries. The SSA region should not expect the biofuels industry to effectively develop in the presence of the multiple investment hurdles that threaten to strangle to death the biofuel industry even before its full potential is realized for the African continent.

The trade policies of SSA countries acknowledge the role of the international markets through bilateral and multilateral trade agreements. The partnership arrangements between sub-Saharan Africa and the EU countries and African Growth Opportunity Act of the US Government are some of the examples of international frameworks that offer greater market opportunity for the SSA countries' biofuels. In fact, some entrepreneurs from outside Africa have already started investing in Africa for the production of energy crops to satisfy the growing demand for biofuels in the EU countries, America and Asia. This is so because the SSA region has vast land and favourable agro-climate for growing energy crops. What is now needed is for the African countries to put in place appropriate policy and regulatory frameworks. Such frameworks would not only promote biofuel production and processing by foreign and domestic investors, but protect African poor households from being displaced from their land, creating hunger through large-scale appropriation of arable land meant for food crop production for growing energy crops.

Trade in biofuels may affect the various stakeholders or sectors through the linkages between the fossil fuel and biofuel prices. At a sectoral level, small-scale rural sector which uses very much less energy than the high-input and mechanized or urban sectors, it is not likely to be exposed as much to the effects of higher fossil fuel prices. However, at a national level, though the low-income developing countries are likely to be adversely affected by the rising prices of fossil fuels. This is likely to be offset by the increased investment in biofuels production that would supplement imported fuels thereby drastically reducing the import bill.

It has also been noted that much as the global economy offers great export market opportunities for the SSA biofuels, a number of challenges also exists outside national policies that need careful consideration. These include low levels of biofuel production, lack of commonly agreed upon international standards and trade barriers such as grades, standards, tariffs and subsidies. In fact, to protect its domestic industry the USA levies a 54 percent tariff on ethanol imported from Brazil, which is the only exporter of bioethanol (Lanely, 2006). Possibly, the SSA countries could be exempted from the US market tariffs through the AGOA initiative by the US government. Unfortunately, the international standards for biofuels (especially for biodiesel) are difficult to achieve given the technologies used in most African countries to produce biofuels.

This analysis, therefore, underscores the need for the countries in the sub-Saharan Africa region to come up with policies, legislation and strong institutional frameworks that will stimulate production and processing of biofuels in a sustainable manner as Brazil and a few African countries[vi] have done (as reported by Howse *et al.,* 2007). In addition, African countries need to build the capacity and skills in production systems through training of experts in biofuels technology. This must be complemented by increased investment in infrastructure such as biofuel production plants, storage depots, service stations and transportation system. Many African countries may take time to develop the local infrastructure for biofuels. However, unless these measures are taken, it will be difficult for most countries in sub-Saharan Africa to establish themselves and take advantage of the growing international biofuels markets.

The effects of international policies on the development of biofuels industry in sub-Saharan Africa

As already argued, the continued increase in the cost of fossil fuels coupled with the quest for securing fuel independence have forced many countries in the EU, USA and Asia to seek innovative ways of using energy crops to produce biofuels as a means to diversify and meet their energy needs. However, many countries in the EU (e.g., the Netherlands, and Belgium) and Asia (Japan and China) do not have adequate arable land to spare for the production of biofuels feedstocks. As such, meeting targets for the share of biofuel in transport fuels will require large-scale production of energy crops. Sub-Saharan Africa and South East Asia will be the focus of biofuel investments in the coming years. Thus, SSA and Asian countries are likely to play an important role in the development of the biofuels sector given their vast natural endowments – climate, arable land and water resources. However, there is need for developing a regional policy framework to ensure that biofuel benefits will not only go to importers but also to the producer countries in the developing world. This should be coupled with national governments making commitments to increase the productivity of the agricultural sector, develop partnerships for information and technology exchange, develop biofuels markets within the region, and provide the resources for research and infrastructural development at the national level.

Despite the clear potential of biofuels to stimulating economic development in Africa, there are a number of uncertainties in relation to its promotion as an alternative to fossil fuels and their effect on agricultural commodity markets. These uncertainties include the nature of agricultural and biofuels policies and strategies that will be implemented to nurture biofuels production from domestic agricultural crops, the pace of technological progress in developing viable "second generation" biofuels production plants that utilize cellulosic feedstocks rather than food and feed crops, and the future price of oil.

So far, the developed countries have committed resources towards research into technologies to convert any type of biomass for biofuels. For example, the EU Biomass Action Plan has put measures in place to prepare for the large-scale use of biofuels by improving their cost-competitiveness through the optimised cultivation of dedicated feedstocks, research into "second generation" biofuels, and support for market penetration by scaling up demonstration projects and removing non-technical barriers (European Commission, 2006). According to section 1514 of the US National Energy Policy Tax Incentives Act of 2005, the Administrator of the Environmental Protection Agency in consultation with the Secretary of Agriculture and the Biomass Research and Development Technical Advisory Committee, will establish an ''Advanced Biofuels Technologies Program'', to demonstrate advanced technologies for the production of alternative transportation fuels. In other words, biofuel advocates have put their faith in technologic advancements to make agriculture a reliable supplier of food while also providing feedstocks for biofuels production.

While biofuels may open a new window of opportunity for creating new jobs in the biofuels industry (e.g., production of energy crops, processing, distribution and marketing), substituting for substantial amounts of imported fuels, and partially satisfying local demand for transport fuels, the consequences of biofuels for food supply and prices remain uncertain - BUT they cannot be ignored. There are increased concerns regarding competition between crops for fuel and crops for food and livestock feed.

Policies and incentives to facilitate biofuels production and marketing in sub-Saharan Africa

In spite of the many technical, financial and policy challenges facing the biofuels sector development globally and Africa in particular, the sector has huge potential for growth. Currently, there is a new scramble for Africa by large-scale investors from the developed world. However, for the African continent to maximize the benefits of the emerging industry, African governments must develop policies and strategies to: (i) promote production of feedstocks without necessarily compromising food security; (ii) attract both foreign and domestic investors in feedstock production as well as refinery processes with conducive internal policy regimes such as tax holidays, rebates, etc within the WTO regulatory framework; and (iii) actively participate in the international arena in terms of biofuels development.

In developed countries, the commonly used support measures for the biofuels industry development include mandatory blending targets and incentives to spur production and consumption of biofuels. These support measures include subsidies, loan guarantees, loans, direct payments and grants. Subsidies may also exist in the form of tax breaks and incentives to construct conversion plants and other capital equipment or to purchase biofuels and biofuel cars. Studies have shown that the cost of subsidizing the growing biofuels sector will be at least partly offset by resulting reductions in other agricultural subsidies .

As biofuels gain prominence in political agendas, agricultural policies will need to be more closely reconciled with energy, environmental, trade and overall economic policies and priorities. Ultimately, the question becomes whether biofuels should be subsidised and, if so, for how long. If biofuels provide net societal benefits (e.g., reduction in greenhouse gas emission) that are not captured in the market system, then there may be a case for subsidies. If, conversely, subsidies become a source of revenue from which a small number of large producers primarily benefit, then subsidies may not be warranted. However, following Brazil's experience, it may be necessary to support to the biofuel sector as a nascent ethanol industry. In other countries – where agricultural, climate and market conditions may make the biofuel industry unviable without governmental support – the question of whether it is appropriate to subsidize developing domestic industries remains. For efficiency considerations, feedstock and biofuel production has to take place in the best suited countries in an environmentally and economically sound manner. Public and private support to research and development may be instrumental to making biofuels production less costly and more competitive. In the long run, it may diminish the need to subsidize the biofuels sector.

The role of African regional economic communities to the promotion of biofuels

The persistent petroleum price increases, which have put pressure on foreign exchange resources and slowed down economic development, have in turn stimulated SSA countries to diversify their energy sources to achieve energy independence. Recently (August 2007), the African Union Commission organized the First High-Level Seminar on Biofuels in Africa at its headquarters in Addis Ababa to discuss the potential and challenges of biofuels in Africa. A political declaration was developed that will, among other things, facilitate: a) the development of an enabling policy and regulatory frameworks for biofuels development in Africa, b) formulation of guiding principles on biofuels to enhance Africa’s competitiveness while minimizing the risks of biofuels development for small-scale producers, and c) encouragement of the engagement of development partners to enable North-South and South-South cooperation in biofuels development. The meeting also called for the engagement of public financing institutions to support biofuels projects, and proposed the establishment of a forum to promote access to biofuels information and knowledge (IISD/UNIDO, 2007). Unlike the European Union, the Africa Union does not have a coherent policy on biofuels.

In 2005, the 15-member Economic Commission for West African States (ECOWAS, 2005) adopted a White Paper whose main goal is to increase by four times during a 10-year period, access to modern energy services for the rural and peri-urban populations. However, due to low technological advancement and the lack of equipment and technical capacity, the policy recognizes the difficulty to follow the Brazilian example of producing ethanol from sugarcane. Rather, it focuses on exploiting some cereals or non-edible plants grown on degraded soils to produce biodiesel such as *Jatropha curcas*. The policy paper does not contain specific strategies for the development of biofuels in the ECOWAS region except to conduct studies to investigate the market potential for biofuels and the conditions for developing industrial crops.

The Southern Africa Development Community (SADC) with 14 member states has recognized the need to reduce reliance on imported fossil fuels by promoting the use of energy crops for biofuels production. Among the SADC member states, Malawi was among the first in Africa to start a major biofuels program in the 1980s, even before Europe began its biodiesel program in the 1990s (Takavarasha, *et al.,* 2005). Malawi started a program of producing ethanol from sugarcane molasses producing 18 million litres of ethanol a year which is blended with petrol. Tanzania and Mali are growing Jatropha for producing biodiesel using the Multifunctional Platform.

However, there are a number of isolated biofuel programs in Africa mainly aimed at reducing pressure on foreign exchange resources that slow down economic development due to persistent petroleum price increases. For example, within SADC, South Africa through SASOL has developed the first synthetic fuel production plant in Africa for the production of liquid fuels such as petrol and diesel from coal and natural gas using Fischer-Tropsch technology. SASOL has a soya biodiesel plant that converts 400 000 tons of soyabeans into 91 million litres of diesel per year. However, biodiesel production is not economically viable without fuel tax-exemption, feedstock subsidies and capital investment support.

Recently, Takavarasha *et al.* (2005) conducted a study on the potential of biofuels in the SADC region. The report outlined three main policy objectives for the biofuels sector. The first objective is to meet at least 20 percent of the total liquid fuel needs of the region from biofuels to ensure national as well as regional energy security. The second objective is to open up new markets through value addition opportunities arising from processing of biofuel crops; and the third objective is to maximize the benefits of the region's comparative advantage for growing tropical energy crops. Despite these policy objectives offering opportunities for countries in sub-Saharan Africa to develop the biofuel sub-sector and take advantage of supplying the required fuels to the region, so far, SADC not done much to implement the recommendations from the report. At present, there are no regional biofuels programs to harness the potential of the SADC, COMESA, EAC and ECOWAS regions. This lack of programs means missing out on the potential of biofuels for rural development through employment creation for smallholder farmers as suppliers of raw materials for biofuel production plants, saving foreign exchange on fuel imports of many countries.

Summary and the Way Forward

The picture that emerges from this study clearly shows that the level of support to the biofuels industry in the developed country is a result of a consolidated regional policy that set targets for significant increase in biofuels mix in the total fuel composition for transportation. This policy is supported by large subsidies provided through relief from fuel excise taxes on biofuels, tax credit for the blending biofuels with fossil fuels, provision of farmer incentives for the production of energy crops, increased investment in research and technology in biofuels.

In contrast, Africa, with its abundant land resources, water and favourable climate for growing energy crops, does not have a comprehensive regional policy on biofuels to regulate the growing industry. This lack of a regional policy and strategy has led to underinvestment into biofuels research and development in Africa. For example, none of the 17 PRSPs reviewed have included any policy statement on biofuels suggesting that biofuels was not a national priority when these PRSPs were formulated. Similarly, many National Energy Policies have either mentioned biofuels in passing or discussed biofuel products under renewable and non-renewable energy sources such as petroleum, biomass, electricity, coal, ethanol, among others. For example, the National Energy Policy for Ghana contains specific strategies for biogas, while ethanol is discussed as part of liquid fuels in the case of Malawi. The energy policies in general do not have explicit strategies, regulatory frameworks and institutional arrangements for the promotion of the biofuels sector with the exception of South Africa's draft biofuels strategy, which contains elaborate strategies for biofuels development in South Africa.

With the growing interest in biofuels worldwide, there is need for national governments in sub-Saharan Africa to develop a clear biofuels policy and strategy to take advantage of potential economic opportunities of biofuels development, while at the same time, protect the environment and rural communities from large-scale expansion production of energy crops for biofuels production at the expense of local needs. In this regard, the regional economic communities in Africa such as ECOWAS, SADC, AU/NEPD and EAC must play an important role in supporting the development of the biofuels industry in Africa. The RECs/AU need to urgently facilitate the development of a framework for a robust biofuels industry in Africa.

As we now live in a global village, any significant shift in the agriculture landscape in the industrialized world will heavily affect Africa countries. Similarly, the effect of rising prices of fossil fuels will heavily impact on oil importing countries in Africa -- biofuels offers some relief on the fuel import bill. Throughout history, agriculture has always adapted to the changing needs of humanity. African agriculture has to change and adapt to meet the demand for both food and fuel.

In the industrialized world, scientists are already developing and testing technologies to increase productivity of agriculture per unit of land or labour in order to meet growing global demand for both food and biofuels. In addition, the biofuels industry is rapidly developing next generation cellulosic technology that will pave the way for scientific breakthrough where non-food feedstocks such as wood chips, algae and switch grass and any other type of biomass will be used as feedstock for producing biofuels. In other ways, the biofuels era is here to stay!

Countries and everyone must face reality, and adjust accordingly in order to survive in the fast changing world. In order to harness the potential of the fast growing industry and benefit from the growing international trade in biofuels, the study urges national governments in sub-Saharan Africa

- to develop comprehensive national biofuels policies and plans in consultation with stakeholders including regional economic communities (RECs) such as SADC, ECOWAS, and COMESA, and with AU/NEPAD;
- to raise the resources for infrastructural development for production, processing, storage, transporting and marketing of biofuels products,
- to commit resources for research and development (R and D), capacity-building and technical support, and
- to establish regulatory and institutional frameworks that provide the incentives for private sector participation in the development of the biofuel industry.

In conclusion, despite the controversies surrounding the viability of biofuels and its effects on the poor, African countries can play an important role in biofuels production, because of their natural endowment – climate, arable land and water resources. At the pace of biofuels development in the developed countries, "inaction" will be costly to African countries not only because they will miss out on the potential benefits that biofuels can offer, but most importantly, land will be taken away from mainstream agriculture for large-scale, export-oriented production of biofuels. This paper appeals to African governments and AU to take decisive action now by investing in science, technology development with emphasis on building human resource capacity and the physical infrastructure to support the product development.

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Endnotes

[i] For practical purpose of this study, we confine our definition of biofuels to include biogas, gel fuel, biodiesel and bioethanol.

[ii] Recently in October 2007, Malawi has imported an ethanol-propelled car from Brazil and has launched a pilot program of modifying the engines of some vehicles to run on ethanol or a mixture of ethanol and petrol.

[iii] Malawi's PRSP developed in 2002 covering the period 2002-2005 has specific strategies for establishing 105 biogas plants by 2005. However, in the current national policy framework (the Malawi Growth and Development Strategy), there is no strategy for the biofuels sector.

[iv] The energy policies are for Botswana, Malawi, Mozambique, Nigeria, Tanzania, Uganda and Zambia, while biofuels strategies are for South Africa and Ghana.

[v] A recent government announcement saying that maize will be excluded as a biofuel feed stock has raised doubts about the effectiveness of the biofuels policy; government has expressed concern about the impact of using maize to make ethanol on the price of food.

[vi] In Africa, efforts to expand biofuels production and use are being initiated or are under way in Benin, Ethiopia, Ghana, Guinea Bissau, Kenya, Malawi, Mozambique, Nigeria, Senegal, South Africa, and Zimbabwe (see http://www.worldwatch.org/node/4081).

[vii] As part of regulation, Malawi's Liquid Fuels and Gas (Production and Supply) Bill of 2004 bars any person from producing ethanol and biodiesel without a licence.

Subtheme 4:
Effective Agricultural Institutions

29. eLearning for Agriculture and Natural Resources Management Education – Some Experiences and Future Directions

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Abstract

Advances in Information and Communication Technology (ICT) and Knowledge Management (KM) nowadays offer new and exciting opportunities also for the teaching and learning of agriculture and natural resources management subjects. Centres of the Consultative Group for International Agricultural Research (CGIAR) are exploring several approaches and tools that facilitate such eLearning in order to reach the ever growing demand for training on these subjects. They range from the development and use of Learning Objects (LO), Learning Objects Metadata (LOM), Learning Objects Repositories (LOR) and Knowledge Banks to the actual teaching support itself using Learning Management Systems (LMS) and various other tools and approaches that facilitate and enhance learning and teaching for lecturing staff at universities and colleges and their students. Important impediments to the adoption of these technologies are the attitudes of those expected to be involved as well as the lack of knowledge and skills to apply these innovative teaching and learning approaches. Young learners tend to be more familiar with computer technology and related communication infrastructure but their teachers have not been trained and are not as experienced in these areas, making it difficult for them to adopt or adapt eLearning for their own teaching. Various eLearning approaches and tools however can complement and enhance the more traditional face-to-face learning and this paper presents some experiences in this area and highlights how the transformation from face-to-face learning to blended and eLearning can be a stepwise process rather than a complete change from traditional teaching and learning.

Key words: eLearning, training, education, blended learning, knowledge banks, learning objects, repositories

Introduction

Advances in information and communication technology and knowledge management (ICT-KM) have dramatically changed the way people teach and learn over the last decades. The use of computers, mobile phones and the internet have made it possible to access an ever growing mass of information that contributes to life-long learning for all. Even though developed countries have been at the cutting edge in these developments, the developing world is quickly catching up albeit at a slower pace due to a less favourable and more costly communications infrastructure. However, the situation is changing rapidly. Those involved in training and education will do well to prepare themselves to embrace new ways of teaching and learning since new generations of learners growing up with computers and information technology will become more demanding in terms of learning content and instructional design. These young learners can be expected to be much more familiar with ICT-KM and have access to relevant learning content from around the globe that those who are expected to teach them are not entirely knowledgeable about. Training staff and resource persons from international research and development organizations too have realized that there are novel and innovative ways to satisfy the ever increasing demands for agriculture and natural resources management learning and thus reach wider audiences of learners.

This paper provides a brief overview of the eLearning situation in Africa and describes a number of eLearning activities currently being implemented by a number of Centres of the Consultative Group for International Agricultural Research (CGIAR) that focus on making learning resources available as International Public Goods (IPG) and allow them to embark on distance and blended learning. The final part gives some practical ideas and suggestions that may inspire teachers and learners at African universities and colleges to start adopting these new approaches and technologies as to improve training and education quality leading to sustainable development.

eLearning and education in Africa

Despite the global importance of ICTs, many developing country teachers and lecturers, particularly the older generation, do not know how or are still reluctant to use ICTs in their teaching and learning activities. The reality on the use of ICT in teaching in African countries is described by Aladejana and Idowu (2006) of Obafemi Awolowo University of Nigeria. Studies showed that at this university, about 81 % of lecturers use ICT in constructing knowledge available from the internet, CD-ROMs, email and databases, while less than 1% use ICT to aid in explaining concepts to students. The use of ICT in education and training requires moving from behaviourism to constructivism. This means that teachers must change from considering themselves being the unique source of knowledge, dispensed to students in traditional ways, to making learning an active process of constructing knowledge through interactive problem-based thinking, reflection and peer collaboration. The barriers to this change include crowded schedules, lack of institutional recognition in performance appraisal systems, attitudes, self perceptions and reluctance to venture into unfamiliar areas. Next to these, there are additional challenges and opportunities that have been researched in Africa and presented at international meetings and conferences discussing building eLearning as described in the following section.

Infrastructural challenges

Poor computing and communication infrastructure in Africa in general, and at African universities in particular, featured high in learning needs assessments of more than twenty-six member institutions throughout Western, Eastern, Central and Southern Africa conducted by ANAFE in 1994, 1999 and 2002 (Temu *et al.,* 2004). However, there is a lot of variation between countries in this area with some being fairly advanced such as South Africa and Kenya and others, like the Democratic Republic of Congo and Sierra Leone for example, that recently emerged from civil strife and as a result do not even have the basic equipment and infrastructure to make use of advances in ICT (Galekwa, 2007). In between, there are many countries that would do well to upgrade and improve existing facilities and infrastructure.

The most common problem cited for this status, are poor internet connectivity and its high cost for relatively low bandwidth. Atieno Aluoch (2007) refers to the 2006 African Tertiary Institutions Connectivity Survey (ATICS) which indicated that universities in Africa pay on average about 4.5 – 36 US $ per Kilobytes/sec/month for bandwidth while internet users in North America, who are on Megabytes or Gigabytes per second speeds, pay less than US $ 10 per month.

Internet access depends on local communications infrastructure. Parastatal telephone operators in many countries often have the monopoly for telephone services, including international communications and internet access, and have been slow or even reluctant in embracing new technology. However, the situation changes rapidly once countries realize that they will be left out of the global economy without it and several projects using optical cabling in Africa will dramatically increase communication speeds and lower the cost. Other innovations are the use of mobile phones and radios that can also link learners to the internet and these open new opportunities for mobile and life-long learning. Makerere University, for example, uses mobile phones to assist in student supervision (Muyinda and Kubega, 2008).

Conceptual and methodological challenges

The development of eLearning or open and distance learning in countries with limited resources not only faces challenges related to infrastructure but also related to integrating eLearning or distance and blended learning into already institutionalized training programmes of non-ICT departments at universities (Mazali, 2008). This requires flexibility in the programme, good e-content developers and instructional designers and the availability of appropriate technology facilitating effective e-teaching and learning. There is also a need for constant quality standard assessment of the e-programmes. These challenges can only be addressed through relevant policy and administrative changes that would also take into account giving incentives to lecturers and technicians to develop e-content and e-resources.

Cultural challenges

In their enthusiasm to develop ICTs, African specialists sometimes overlook these challenges which are linked to developing locally relevant eLearning content and material. Clayton and Torzeli (2007) stressed that "*Failure to recognize the cultural and worldview influences in the ICT field, which are predominantly western, minimizes the possibility of shaping the technology to fit the implementation cultural context, and encourages the notion that society and culture rather should adapt to technological changes*". The philosophy in the development of ICT models for Africa should be based on socio-constructivism which views the utilization of knowledge in the context of social relationships between members of a community.

Despite all these challenges, eLearning and Open and Distance Learning (ODL) can be a more inclusive and cost-effective way of teaching as opposed to the traditional 'chalk and talk' ways of teaching in fixed geographical locations (Okuro Gunga, 2007). NEPAD recognizes the central role of technology in the future prospects for the continent. Pan African networks like ANAFE are also interested in regional and large scale initiatives. To develop these, African countries are building several political and economic sub-regional partnerships to harness the eLearning and Open Distance Learning (ODL) expertise existing in the continent. Instead of individual and isolated efforts on developing eLearning and online education, tertiary African institutions are actively engaged in establishing South–South and North–South collaboration in eLearning/open distance learning. This collaboration provides some good opportunities for African institutions, some of which include:

- The Agence Universitaire pour la Francophonie (AUF) is an important driver of the development of distance learning programmes in francophone West and Central African Universities (Loiret, 2006; Thebault, 2007). The AUF objectives are to; a) increase access to scientific and technical documentation, b) provide academic staff and students with opportunities for blended and distance learning, and c) develop and facilitate access to tools for knowledge generation and diffusion.

- The African Virtual University (AVU) is a pan-African intergovernmental organization whose aim is to significantly increase access to quality higher education and training through the innovative use of ICT. As an African organization, the AVU has the mandate to increase access to tertiary education and training using Open Distance and eLearning (ODL) methodologies. Over the last ten years, the AVU has established the largest network of ODL institutions in Africa. The AVU has more than 50 partner institutions in over 27 countries in Africa. Its headquarters is in Nairobi, Kenya and there is a regional office in Dakar, Sénégal, in West Africa.

eLearning and the CGIAR

The Consultative Group for International Agricultural Research (CGIAR) is a strategic partnership of over 60 members supporting 15 international agricultural research for development centres located in Africa, Asia, Latin America, the United States of America and Europe. The overall goal of the agricultural and natural resources management research of the CGIAR is to improve the livelihood of low-income people in developing countries through reduced poverty, food insecurity, malnutrition, gender inequality, and child mortality, to help cope with HIV/AIDS, and to foster better institutions, policies and sustainable management of natural resources of particular importance to agriculture and poor people. The CGIAR is a provider of international public goods through agricultural research aimed at alleviating poverty. Capacity building is a key activity to meet the overall goals of the CGIAR. It provides opportunities for capacity strengthening to enhance innovation and learning of knowledge-intensive organizations in developing countries, for instance, through the development of tools and methods for knowledge management and structured approaches to needs-based training (CGIAR Science Council, 2005).

The knowledge generated by the research of the CGIAR Centres as well as the resulting learning resources for capacity building are made widely available to individuals and organizations working for sustainable agricultural development throughout the world (CGIAR Science Council, 2005). Already in the mid-1990s the CGIAR has recognized the important role of knowledge management and knowledge sharing at a strategic level to strengthen the effective acquisition and exchange of information and knowledge in the CGIAR (CGIAR Centre Directors Committee, 1994). Since then, the CGIAR has improved the access to its global public information goods with a strong focus on content and knowledge sharing (Rudgard *et al*., 2007).

In the early 2000s, the CGIAR established the ICT-KM Programme (http://ictkm.cgiar.org) with the goal to provide its information users worldwide with simple but enhanced access to the vast array of scientific data, information and knowledge (CGIAR System Office, 2006).

New thinking in learning resources development and accessibility

The ICT-KM Programme aims at researching advances in technology for use in several areas of CGIAR research for development, including capacity building and strengthening through training and education. As such, the programme supports a number of eLearning initiatives collaboratively carried out by the training departments of the Centres. One of these projects, the On-line Learning Resources (OLR) project looked at advances in the development and accessibility of learning resources using Reusable Learning Objects (RLO) and their storage in knowledge pools or repositories. Several of these are now in existence (MERLOT, GEM, EduSource, EDNA and ARIADNE) in developed countries and the use of Learning Objects Metadata (LOM) allows users to discover these through 'federated' searches.

RLOs are based on a new way of thinking about learning and provide a digital educational resource that can be reused, scaled and shared from a central online repository in the support of instruction and learning (Grunwald and Reddy, 2007). Each RLO supports a single learning objective. They vary in size, scope and level of granularity ranging from small chunks of instruction to a series of combined resources to provide a more complex learning experience. Figure 29.1 illustrates the concept of Reusable Learning Objects.

The main characteristics of RLOs suggested by various authors (Wiley, 2002; Barritt and Alderman, 2004; McGreal, 2004; and Koohang and Harman, 2007) are as follows:

1. Digital / web-based – 24/7 accessible
2. Reusable – RLOs can be used in multiple context; for multiple purpose; at multiple times (e.g. RLOs can be used to teach an undergraduate or graduate course, short course, certificate course, or extension/outreach)
3. Self-contained – each RLO focuses on a specific topic/learning objective
4. Small in size – to focus learner's attention (2-15 minutes)
5. Standardized – RLOs follow the same organizational structure; free of look- and feel of formatting to be reused in multiple delivery media
6. Flexible – RLOs are easy to update; provide access to quality teaching and learning resources for a wide range of learners
7. Interoperable – RLOs operate across different platforms and communicate with other tools to build larger modules, courses or curricula
8. Suited for new types of learners – net-generation learner; learner-centred
9. Cost-effective – avoid duplication of learning materials; provide intellectual capital.

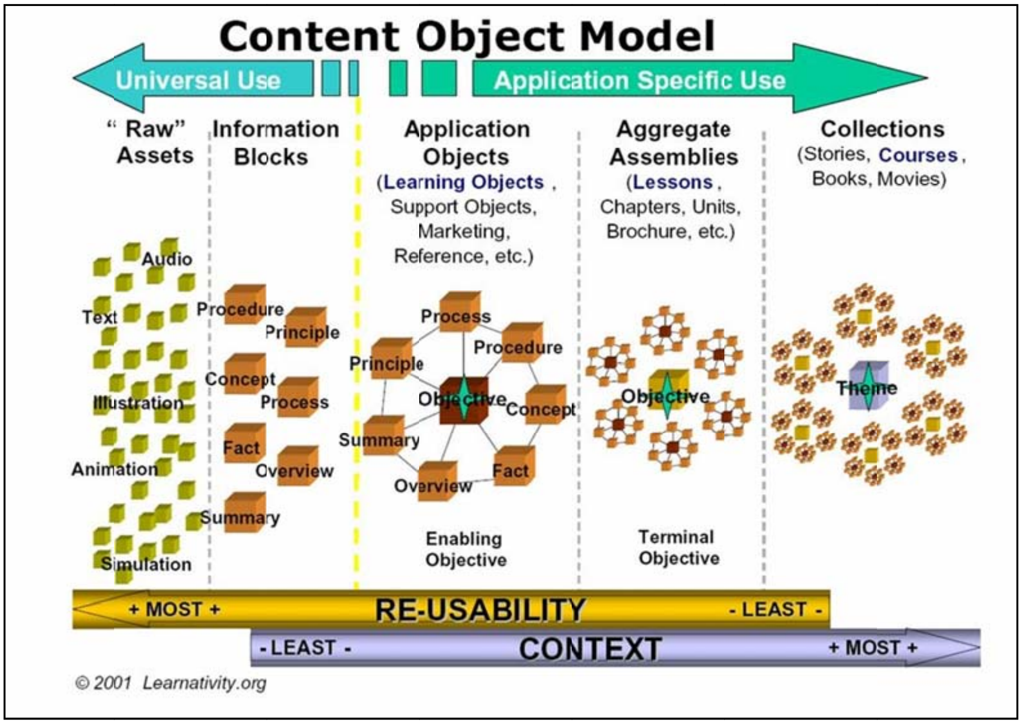

Figure 29.1. Reusable Learning Objects (RLOs) – reusability and context. Source: http://www.learnativity.com.

Searchable – RLOs are tagged with metadata (information that describes the RLO).

Metadata is a simple term for a powerful concept and is most easily defined as information about information. One of the most common examples is that of the information in libraries card catalogues. That content is metadata. Another example is the information on any packaged food item that tells what is inside, to who makes it, and a full breakdown of every part of the contents. Metadata learning standards are for the categories or "elements" for all the information wanted for every "learning object" or content out there and having an agreed upon standard set of metadata elements so that the person or system receiving this information can read and understand. Standards are specifications approved by an open accredited standards body. Learning standards include those covering learner profiles, course sequencing, course interchanges, and learning object metadata, such as those from the Institute of Electrical and Electronics Engineers (IEEE) Learning Technology Standards Committee (LTSC). Figure 29.2 illustrates the concept of Learning Object Metadata (LOM).

Some on-going eLearning activities 1

The CG Centres are committed to leveraging strategic partnerships for distance education and online learning to scale up CG research outputs for increased impact. These partnerships are focused on contextualizing content, curriculum development and course delivery to address gaps in capacity for agriculture and natural resource management research for development. An inventory of open learning activities revealed that Centres are gaining experience with diverse online and distance learning tools and mechanisms. Some of these are repositories for learning resources, others support formal learning or focus on the delivery of short courses and workshops using eLearning tools and approaches. The following paragraphs highlight a number of them.

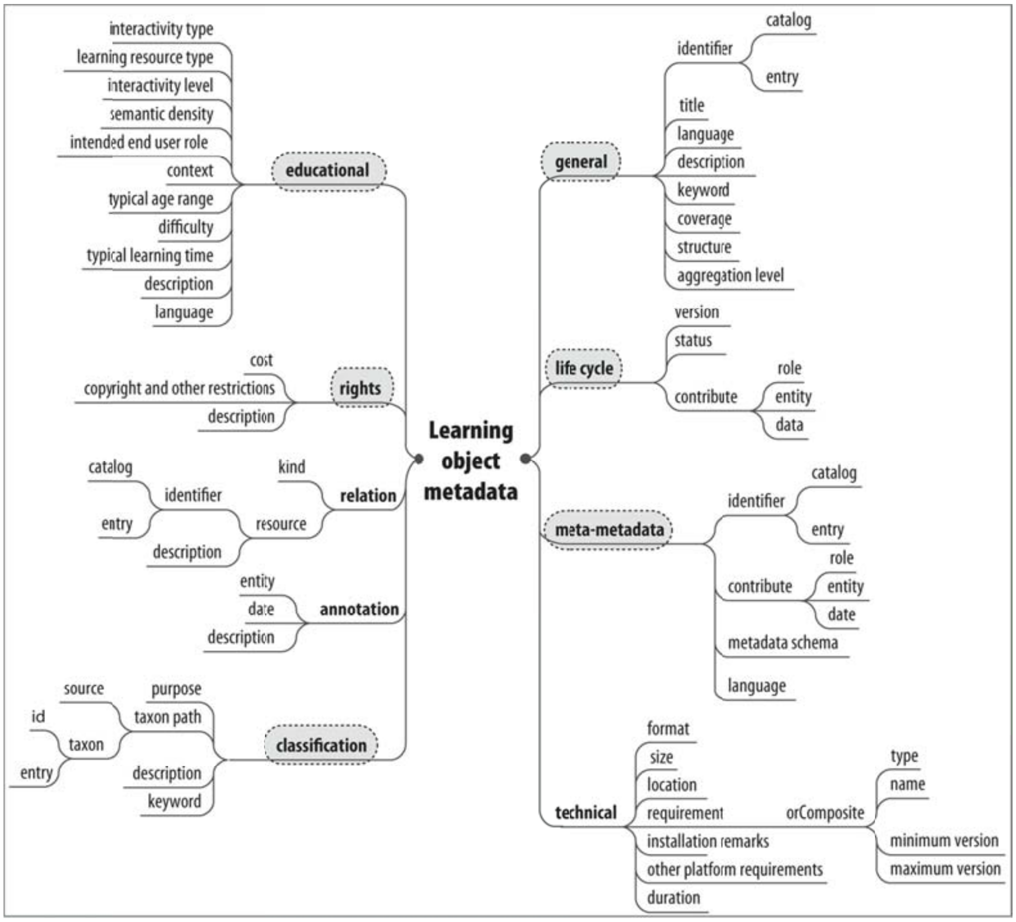

Figure 29.2. Learning Object Metadata.

- **On-line Learning Resources (OLR)** (http://learning.cgiar.org): The World Agroforestry Centre (ICRAF) and CIP (International Potato Centre) are coordinating the CGIAR OLR project under the ICT-KM Programme (Zschocke and Beniest, 2006). This project aims at forging a virtual CGIAR training community and developing approaches, tools and methods that can be used by such community to promote the use of ICT-KM in CGIAR training and education. The first phase of this project focused on the development of a repository that would store the available learning resources from the CGIAR Centres as to allow their discovery using the internet - worldwide web. This needed to be done using international standards and approaches described above if these resources are to be searched for among many similar existing repositories. In order to better describe the agricultural learning resources of the CGIAR, the OLR project needed to develop an application profile based on IEEE LOM (Beniest, Paisley and Zschocke, 2005). This application profile then served to develop the repository. Since the main role of the CGIAR is to develop content and provide information, it was decided to enter into a strategic partnership with ARIADNE – the European Knowledge Pool since they have the technical expertise to deal with the information technology needed. This repository is now also linked to a Learning Management System (LMS). It was decided to use an open source software programme (Moodle) for this rather than proprietary LMS packages that would be expensive in terms of licensing. Moodle is simple, flexible and easy to access for people with moderate to good ICT knowledge. It also encourages collaborative learning as learners communicate and interact with each other through a variety of activities and means, including forums, chat and e-mail. CGIAR training staff can thus offer short courses 'on-line' using the available learning objects or developing and storing new ones for such courses. A major concern in having such widely available on-line resources is that there must be strict quality standards to be adhered to as not to compromise the Centres contributing to this. The project thus initiated the development of a quality standards in CGIAR training and education manual that will be available soon.

- **Cereal knowledge banks (**http://www.knowledgebank.irri.org/): The IRRI-CIMMYT (International Rice Research Institute – International Institute for Maize and Wheat Improvement) alliance endorsed an integrated Cereal Systems Knowledge Project to use the example of IRRI's Rice Knowledge Bank to develop a Cereal Knowledge Bank (CKB) which compiles information on the world's three most important cereal crops – maize, wheat and rice. The CKB is a simple HTML-based tool which includes a global digital extension service for those who provide information and support for farmers, such as extension specialists and NGOs, and also a comprehensive, digital rice/maize/wheat-production library containing an ever-increasing wealth of information for training in the form of fact sheets, field practices and diagnosis tools, e-□courses, and training materials. The CKB is designed as a demand-driven system that delivers credible information in value-added form. To those who do not have access to the internet, the CKB will be provided on a CD-ROM. Both IRRI and CIMMYT are also actively supporting development of individual country knowledge banks with country-relevant information in local language(s) which are managed by local consortia of scientists, extension personnel and government officials. Figure 29.3 shows the CGIAR cereals knowledge bank.

Figure 29.3. CGIAR Cereals Knowledge Bank.

- **Virtual genebank:** Bioversity International (formerly the International Plant Genetic Resources Institute (IPGRI)) is leading efforts to develop a 'Virtual Genebank'. This is a platform for an online knowledge base of best practices for genebank management and decision making tools will be integrated to support capacity development for CG Centre and NARS genebank personnel. The Knowledge Base in an activity of the System-wide Genetic Resources Program (SGRP) for "Collective action for the rehabilitation of Global Public Goods in the CGIAR Genetic Resources System." It will provide a user-friendly 1-stop shop for online access to procedures, standards and practices for managing crops held in common across the CGIAR centres and selected NARS genebanks. CG Centre and NARS genebank managers are participating in the design and validation of the best practices and the CG Centre capacity strengthening community is providing guidance on the learning components of the knowledge base. A prototype, using Musa and wheat as model species for clonally propagated and seed crops, has been developed and is being validated by partners.

- **Support to university curriculum development** (http://www.openaguniversity.cgiar.org): IFPRI and ICRISAT (International Food Policy Research Institute and International Crops Research Institute for the Semi-Arid Tropics) are spearheading the CGIAR AGROCURI (Agricultural Curriculum Development) Programme in close collaboration with other CGIAR Centres. This programme is working to bring together global agricultural research systems and partner institutions to create, organize, and share agricultural knowledge in order to increase the productivity and sustainability of food and agriculture systems in sub-Saharan Africa and South Asia. Using open-access and collaborative networking approaches to knowledge creation and sharing, the AGROCURI programme's primary mission is to strengthen the capacity of university partners and to train skilled professionals, post-graduate and undergraduate students. The initial focus will be on agricultural economics and ecology but more subjects will follow.

- **Virtual academy for the semi-arid tropics** (http://www.icrisat.org/vasat/): ICRISAT hosts the Virtual Academy for the Semi-Arid Tropics (VASAT) in collaboration with the International Livestock Research Centre (ILRI) and a number of other partners. This is a strategic coalition for information, communication and capacity building, operating in South Asia (SA) and West and Central Africa (WCA) in partnership with the Desert Margins Program (DMP). VASAT links and mobilizes stakeholders for drought mitigation in the semi-arid tropics. It is an innovative and cost effective medium to educate and support a critical mass of rural women and men spread across vast geographical areas by informing them about drought and desertification. It is a response to the need of the United Nations Convention to Combat Desertification to implement a communication strategy for combating drought and desertification. Figure 29.4 shows the virtual Academy for the Semi-Arid Tropics (VASAT).

Figure 29.4. The Virtual Academy for the Semi-Arid Tropics (VASAT).

- **An on-line course** http://www.bioversityinternational.org/Publications/pubfile.asp?ID_PUB=1251: CIAT (International Centre for Tropical Agriculture) and Bioversity International have documented experiences from collaboration on an eLearning course on "*Ex-situ* conservation for genebank managers" in Latin America. A 2007 evaluation report describes the activities of a collaborative association between CIAT, Bioversity International, the Universidad Naçional de Colombia (UNC), and the Network of Institutions Dedicated to Teaching Agricultural and Rural Development Policies for Latin America and the Caribbean (REDCAPA). The aim of this report is to document the association's activities and analyse them to extract the lessons learned in the process, thereby orienting this initiative's future activities and serving as a point of reference for others. It gives some important conclusions and recommendations regarding the planning and preparation of such a distance learning course, its development and implementation and the need for thorough monitoring and evaluation.
- **Blended learning** (http://www.statistics-training.org/course/view.php?id=7): CGIAR training staff does realize that it is impossible to teach practical and contextual subjects such as agriculture and natural resources management solely in an online environment and thus the latter can only be used for certain parts of the learning process whereas others will continue to require face-to-face problem solving learning events. Such a blended learning approach offers great opportunities to make the best of both the on-line and face-to-face environments. ICRAF spearheaded the development of a blended learning event on 'Research methods – Thinking Scientifically' which proved highly successful in offering this course through six weeks facilitated online learning using Moodle as the LMS followed by a one-week face-to-face problem solving workshop. The course brought together 38 MSc and PhD students conducting their thesis research in collaboration with several CGIAR Centres and aimed at changing students' and supervisors' attitudes towards high quality research for development and also to impart knowledge and skills needed to achieve this (Beniest *et al.,* 2008; Vandenbosch *et al.,* 2008). Figure 29.5 shows the LMS Moodle for the research methods blended course.

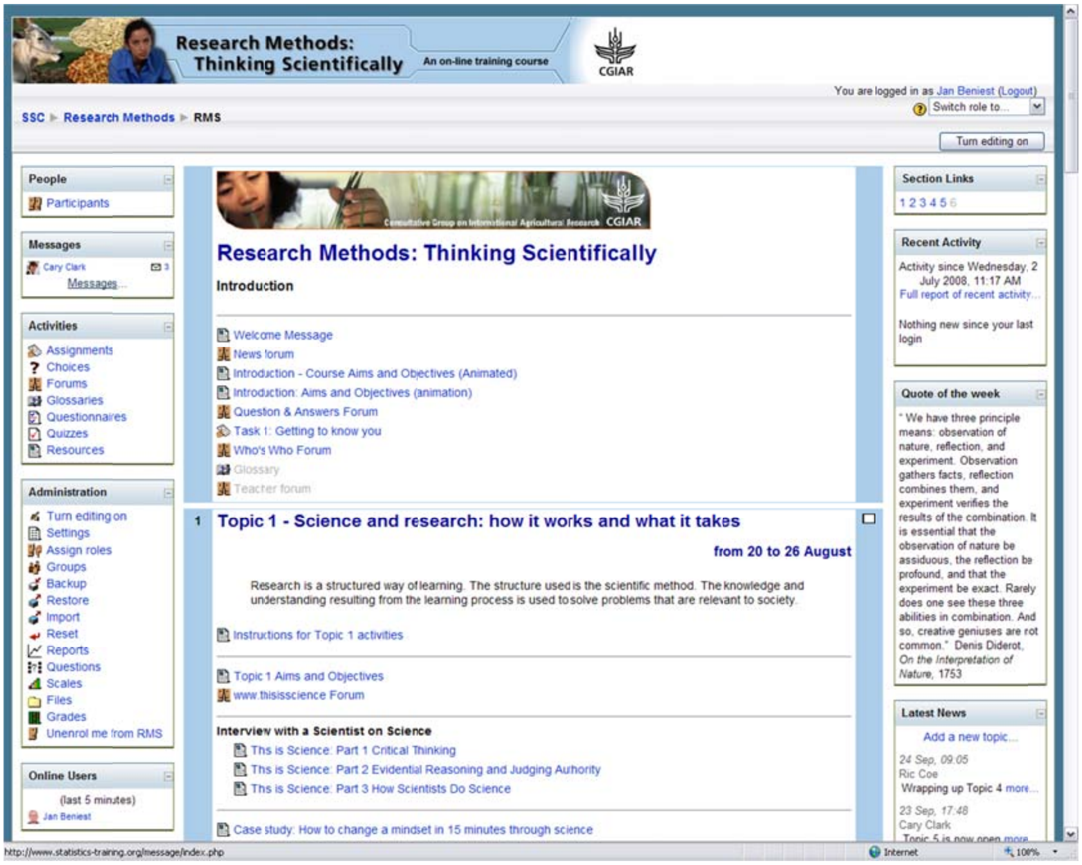

Figure 29.5. The LMS Moodle for the research methods blended course

1. Adapted from 'CGIAR Capacity Strengthening Community – Joint action to improve context and impact of CGIAR research'. Flyer distributed during the CGIAR Annual General Meeting in Beijing China, December 2007.

Introducing eLearning at African Universities and Colleges

African universities and colleges may find e-learning a practical and efficient way to enhance capacity strengthening in climate change issues and to reach larger and more remote audiences. Several universities and other institutions are already researching, exploring and testing opportunities such as knowledge banks, learning object repositories, online courses and blended learning courses, and several others are planning to do so in the near future.

Since attitude change is a major hurdle, the move from traditional classrooms to e-learning can be made in small steps making change easier to accept. Blended learning environments for example enable resource persons and instructional designers to develop the skills needed for e-learning in small increments: they can move small sections of a traditional face-to-face course online as they develop the needed e-learning skills. Given all the possible formats of e-learning and the wide variety of contexts, it is difficult to identify specific best practices in introducing e-learning. Below are some powerful starting points which lecturers at African universities and colleges could use, based on literature (e.g. Driscoll, 2002; Rossett, Douglis and Frazee, 2003) and the experiences at African universities and colleges and the CGIAR described above, in order to gradually introduce elearning in their climate change education programmes. But introducing elearning at a university or college also requires institutional support, including leadership and strategic planning.

Some starting points for lecturers at African universities and colleges

Information and references from books and research papers online

Nowadays there are many books, journals, Open Educational Resources (OER), grey literature and other publications that are freely available online and will help teachers and learners to develop their own learning resources or can serve as additional references providing more detail on a subject . There are also many books and other publications available, free and at cost (for example at www.amazon.co.uk) on eLearning, learning objects, repositories and instructional technology that will give newcomers to these fields an insight of what this is all about.

CGIAR Virtual Library (http://vlibrary.cgiar.org): This is a global link to leading research on food crops, livestock, fisheries, water resources, forestry, plant genetics, and food and nutrition policy.

- **Google Books** (http://books.google.com): Google has digitized many books from library collections, including books related to climate change. If the book is out of copyright, or the publisher has given permission, you'll be able to see a preview of the book, and in some cases the entire text. If it is in the public domain, a PDF copy can be downloaded.

- **AGORA** (http://www.aginternetwork.org): Access to Global Online Research in Agriculture (AGORA) is a programme to enable developing countries to gain access to an outstanding digital library collection in the fields of food, agriculture, environmental science and related social sciences. AGORA provides a collection of 1,278 journals to institutions in 107 countries. AGORA is designed to enhance the scholarship of students, faculty and researchers in agriculture and life sciences in the developing world.

- **OARE** (http://www.oaresciences.org): Online Access to Research in the Environment (OARE) enables developing countries to gain access to one of the world's largest collections of environmental science research. Over 1,300 peer reviewed titles are now available in more than 100 low income countries. Research is provided in a wide range of disciplines, including climate change.

- **DOAJ** (http://www.doaj.org): The aim of the Directory of Open Access Journals (DOAJ) is to increase the visibility and ease of use of open access scientific and scholarly journals thereby promoting their increased usage and impact. The directory aims to be comprehensive and cover all open access scientific and scholarly journals that use a quality control system to guarantee the content. In terms of climate change, the directory contains journals such as *Carbon Balance and Management*.

- **JSTOR** (http://www.jstor.org): JSTOR is actively preserving over one thousand academic journals in both digital and print formats, and continues to expand access to scholarly works and other materials needed for research and teaching globally. JSTOR has waived participation fees for academic, government, research, and not-for-profit institutions in Africa.

Consult available learning resources repositories and websites

Links to online learning resources can be provided to learners to use before, during or after traditional face-to-face modules or courses. Below are some free websites of repositories that can be helpful in this process. Some of these also allow you to upload your own materials and resources. The same materials and resources can then be used in various eLearning activities.

- **CGIAR Online Learning Resources** (http://learning.cgiar.org/resources): provides instructors and learners with quick and easy access to the agriculture and natural resource management learning resources of all CGIAR Centres and offers support and assistance to an international training community of practice. More details can be found in the previous sections of this paper.

- **MERLOT African Network (MAN)** (http://man.merlot.org): This is a network of African higher education institutions affiliated with the Multimedia Educational Resource for Learning and Online Teaching (MERLOT). MERLOT is an international cooperative of professional discipline communities that collects and makes freely available high-quality online resources to improve learning and teaching.

- **WikiEducator** (http://www.wikieducator.org): This is a website that provides free e-learning content that anyone can edit and use. Anyone can edit content and make contributions. Use of WikiEducator is free, and users do not need a high level of technical skills.

- **OER Commons** (http://www.oercommons.org): This is a global teaching and learning network of free-to-use resources. In terms of climate change, it contains several useful resources, including a video segment adapted from NOVA explaining the difference between weather and climate and featuring analysis revealing that Earth's climate has changed much faster than previously believed.

- **EcoLearnIT** (http://ecolearnit.ifas.ufl.edu): This is a framework of various tools that guide through the process to create a re-usable learning object (RLO). EcoLearnIT is a peer-reviewed system that includes e-learning materials based on the RLO format. A peer-review panel and editor evaluate the submitted RLOs before they are published in the digital library. After RLOs are accepted for publication they are hosted in the main RLO repository that is accessible to all users of EcoLearnIT. The thematic range of RLOs included in EcoLearnIT is broad with a focus on soil, water and environmental sciences including carbon sequestration and global warming as a topic area.

FAO Capacity Building Portal (http://www.fao.org/capacitybuilding): This portal highlights FAO's learning resources, learning services, and featured sites highlighting specific initiatives in capacity building. The learning resources section presents various types of learning resources published by FAO in a range of languages and media. The metadata application profile for FAO’s learning resources is well documented and assures that standard nomenclature is used enabling learning resources to be described and shared in a common way and, therefore, allowing for increased accessibility of the resources from other major learning portals.

- **UNESCO Open Training Platform** (http://opentraining.unesco-ci.org): This platform aims to empower trainers and/or trainees with free resources, offer them a structured collaborative space to share their training but also to promote and value the "open" training materials, which are freely and openly accessible for trainers and self-learners to use and re-use for non-commercial purposes such as teaching, learning and research. Content categories on the platform include agriculture and environment and a simple search for climate change returns several interesting results.

- **UNEP MENTOR Platform** (http://www.unep.org): The objective of the Marketplace for Environmental Training and On-line Resources (MENTOR) is to disseminate appropriate tools, guidelines, methodologies and best practices in data collection, analysis, monitoring, integrated environmental assessment, early warning and observation, information networking, and support online training in the use of these tools and methodologies. Climate change will be one of the main topics. The platform is currently being set-up and resources including their metadata are being uploaded. The platform is expected to be ready for testing by October 2008 and in full operation by 2009.

Take an e-learning course

One of the best ways to get familiar with the opportunities and limitations of eLearning and blended learning is to take a course by eLearning yourself. A wide range of e-courses are currently being offered worldwide, so you could register for a course related to any topic that is of interest to you. A 'Google' search of the internet will probably easily identify a course that suits your needs.

Evaluate open-source learning management systems

After taking one or several online courses, it will be possible to look at the way these are offered and what tools are being used. Several excellent open-source learning management systems are now available and are viable alternatives to commercial products. Two of the most widely used open-source learning management systems are Moodle and Sakai. Open source software movements are in tune with the collaborative nature and intellectual freedom characteristic of academic institutions worldwide.

Attend an eLearning conference or workshop

Being more familiar with aspects of e- and distance learning, you may want to attend one of the many conferences, seminars and workshops on the subject during which people share ideas, experiences, tools and network with colleagues. These meetings can enable lecturers and other staff at African universities and colleges to further enhance their knowledge and expertise. Key events include the annual eLearning Africa conference on ICT for Development, Education and Training, the biennial Pan-Commonwealth Forum on Open Learning, and the annual International Conference on Technology Supported Learning and Training (Online Educa Berlin).

Maximize e-mail and messaging, develop communities of practice

E-mail distribution lists, threaded discussions and mobile messaging can be used before, during, and after traditional face-to-face courses. The World Agroforestry Centre for example has been creating discussion spaces in Dgroups (http://www.dgroups.org) for several courses where participants expressed a need to continue communicating and exchanging information and opinions with each other. DGroups is an online home for groups and communities interested in international development. In DGroups, one can find the online tools and services needed to support the activities of a team, a group, a network, a partnership or a community. Members share literature, experiences and opportunities for training and funding, post updates on the implementation of their personal action plans, and ask for advice. Google and Yahoo groups also allow for the development of virtual communities.

Put assessments online

One of the easiest places to start is to move a multiple-choice test or assessment online. This allows lecturers to automate scoring and makes it easier to track and report scores. There are many tools and websites available for this on the internet.

Move components of a traditional face-to-face course online

Instructional designers can review a training course programme, chunk it into modules, and determine the best medium to deliver those modules to the learner. Learning resources which are already available in repositories (e.g. Cereal Knowledge Bank, CGIAR Online Learning Resources) can be made accessible within a blended learning or e-learning environment. Learners may have to complete modules online before being allowed for the face-to-face parts of the course, ensuring learners show up prepared. Online sessions can also be organized after a face-to-face course as a way to extend the classroom experience. In climate change education and training for example, this can help learners with problems they encountered in the field when applying the knowledge and skills gained.

Course design

A significant portion of time for e-course design should be spent on assessing learner needs and special challenges that learners may face in an online learning environment. Developing a comprehensive plan on instructional strategy to meet the needs of learners can be a strong determinant of the success of online programmes in a global context (Ally, 2004). Learners' technological resources such as online course accessibility need to be considered (Larsson *et al.,* 2005). Similarly, it is critical to evaluate and assess the needs of the resource persons participating in the online programme. Providing professional development for resource persons to improve their skills and knowledge regarding online pedagogy can help ensure the success of online courses.

Early in e-course design, many lecturers thought putting their lecture notes on the web was an eLearning course. This can indeed be one of the first steps towards eLearning, but proper eLearning courses need to be carefully designed to provide engaged learning, and should use learning strategies and provide learning outcomes.

Institutional support

Leadership

It takes institutional support within your college or university, with resources, to make an e-learning course or programme function successfully. A leader with institutional authority must champion e-learning for it to reach its full potential. As with many innovations, high level administrative support is necessary to bring about the required organizational change within the college or the university. Leadership must be applied for e-learning to be successful due to the required strategic decisions (Kofahi and Srinivas, 2004). However, administrators are not always comfortable with the notion of elearning. Perhaps it is because of its ill-defined nature, or its non-traditional, decentralized student body, or its high initial investment costs, or maybe the administration's lack of appreciation for a different way of educating.

According to Haughey (2003), there are three aspects to the change process:

1. The realization of the need for change
2. The mobilization of internal and external support for the change

The actual implementation of the change and its integration into the on-going operations of the organization.

The first and third aspects could be achieved by faculty lecturers and staff; it is the second aspect - the mobilization of the university or college - that requires the institutional leader and administrative champion.

Strategic planning

The literature also emphasizes the importance of strategic planning in elearning. Senior administrators in universities and colleges must invest in a strategic plan for e-learning. Management must provide leadership in developing this plan for the institution as a whole. In the rush to get courses online, many institutions missed the planning phase. Even in institutions that are not currently working under a strategic plan for elearning, the planning process should still be performed. The process helps to discover inadequacies and to realign priorities. Creating a strategic plan for elearning is a multistep process and several models have been proposed which can easily be adapted and adopted by African universities and colleges (e.g. Shelton and Saltsman, 2005). The initial development of an e-learning course or programme is costly in financial and human resources. It is important that your institution be committed to providing that support, and a strategic plan can help make it work.

Conclusion

Globally, the learning world is evolving rapidly as the result of advances and innovations in communication and computer technology. Developed countries are fully embracing this which has dramatically influenced teaching and learning at universities and colleges in these countries. Knowledge is now universally available at any time and from any place and thus the role of teachers, trainers and learners needs to change. They are no longer the unique source of information to be dispensed to students in a classroom context since the latter are now growing up in an increasingly wired and wireless world with a lot more information at the click of a few buttons than what is available in the classroom. The questions are no longer why Africa should join this revolution or what the possible constraints and problems are but rather 'how soon?' if the continent does not want to lag behind in the global knowledge-based economy. Computer and information technology departments at learning institutions are quicker to adopt these changes than other departments such as agriculture, forestry and livestock sciences. This is partly related to the fact that these subjects are still of a very practical and highly contextualized nature that cannot always be adapted to eLearning but there are many ways to overcome this. The biggest impediment seems to be the attitude of an older generation of teachers and trainers who did not grow up with these developments and are thus hesitant to adopt this in their teaching and training. CGIAR Centres and several institutions in developing and developed countries have taken steps to explore and use ICT in the context of their learning activities and other learning institutions are encouraged to do so as well not only for emerging topics and subjects of importance such as climate change and global warming but for any agricultural or natural resources management one. The main challenge is to not let the technology drive this but the wealth of on-line information and innovative technologies adapted to the continent's social and learning environment.

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30. Positioning Agricultural Research for Effective Contribution to Climate Change in Sub-Saharan Africa: Enhancing 'Knowledge to Action' and 'Action to Knowledge'

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Abstract

Africa's development is and will continue to be greatly affected by the potential threats of climate change, leading to changes in the continent's development trajectory including disruption of the food systems. The expected changes are complicated by the pursuit of divergent interests by social groups, private sector and the governments operating at different levels. In this review paper, we seek to provide a framework for promoting "actionable knowledge" on climate change at national, regional and global scales. Climate change negotiations and collective action form the international level domain. Divergent interests of social groups, private sector and governments constitute the national domain. In the climate change realm, it is obvious that interactions and feedbacks between 'internal' and 'external' domains are more inclined towards shaping dynamics within the African domain. The neutrality and carbon offsetting myth, carbon financing mechanisms, technology transfer, capacity building, and now reduced emissions from deforestation and ecosystem degradation (REDD) are differently perceived at the interface of the internal and external domains. The focus of this paper is not internal-external domains' interface, but how agricultural education can be enhanced so that knowledge generated can effectively be used by different sub-units within the internal domain in translating climate change adaptation into reality. How that translation should be done is a challenge that developing country grapple with, especially when external sub-units use trade and funding to pull the 'strings'. In such a scenario, Africa, as an internal domain, has its interests influenced by the sub-units of the external domains. If we consider countries as units in the internal domain, governments as well as being a facilitator and implementer, become principal agents in organizing and pushing for the mainstreaming of adaptation mechanisms for climate change. These roles of government are complicated by the urgency of meeting short-term requirements *vis-à-vis* a large-scale longer-term donor climate change adaptation. Could agricultural research play a bridging role in ensuring that sub-units within the internal domain have positive feedbacks that promote climate change adaptation? This paper focuses on how agricultural education can be refocused and re-structured so as to build on what we already know and build a strong foundation for future learning.

Key words: climate change, knowledge to action

Introduction

The potential impacts of climate change is seen at different scales in both developed and the developing world, and such different perspectives shape their understanding of the common differentiated responsibilities. It is, however, generally envisaged that the effect of climate change on food and environment will worsen over space and time. Tremendous information and knowledge have been generated by the scientific community on potential impacts of climate change, yet little has been done to mainstream climate change adaptation into national agricultural planning and implementation. This failure is partly attributed to the nature and scope of agricultural education. Climate change is predicted to influence rainfall patterns and weaken farmers' adaptive capacity (Seth, 2007). Hotspots and typologies of ecosystem services have been predicted to change as a result of climate change and climatic variability (Yatich, 2008).

The current status of livelihoods, food security, ecosystems, poverty, natural resources, and levels of resilience are predicted to worsen. Cushioning such shifts will be dependent on vulnerability levels, adaptive capacities and how well we look from inside out for lessons and experiences. How geo-political regimes pursue adaptation to climate change will determine how agricultural systems withstand future shocks. Achievements of the Millennium Development Goals (MDGs) have been depicted to be dependent on climate change as well (Gomez-Echeverri, 2007). These threats have led to externally driven initiatives (e.g., the 'climate change adaptation in Africa' initiative by the IDRC, several carbon pilot projects in different locations by the African Centre for Technology Studies and climate change theme projects by the CG centres) with minimal participation of African institutions, including universities. The Stockholm Environment Institute (SEI) (2008) warns that low levels of economic activity render African countries disproportionately vulnerable to climate change impacts. The African Development Bank (2008) estimated that greenhouse gas emissions from fossil fuel use in Africa is only about three per cent of total emissions. This is negligible compared to the amount of greenhouse gases (GHGs) released to the atmosphere by countries of the North, operating at ecological deficits, and emerging economies like China, India and South Africa. However, SEI (2008), argues that per unit gross domestic product (GDP) produced African economies are the most CO_2 intensive in the world at 1.65 kg of CO_2 equivalent per US $ of GDP. SEI (2008) further attributes the low emissions to low levels of economic activity on the continent resulting in low aggregate emissions. This is the paradox that shapes Africa's position on the global debate. So what will African efforts contribute to reducing greenhouse gas emissions if it only contributes three percent? Also, has the climate change negotiations translated into technology transfer? And can agricultural education be positioned to shape climate change adaptation? Such questions are significant and will continue to shape the climate change agenda and Africa's position on climate change.

Social groups, the private and public sector organizations recognize climate change as a threat multiplier with varying impacts on their pursuits of economic wealth and political power (Reed, 2004). The groups' divergent interests, subsequent power relations and competitions in the face of declining resources are likely to weaken collective action for climate mitigation and adaptation at country levels. Multiple stakes and multiple perceptions on rights and interests, and power relations at the local level, the fundamental focus of mainstreaming climate change adaptation, are often ignored. Collective action at the international level is complex, shaped by chauvinistic interests and is often puzzling. Given this scenario, would agricultural research provide opportunities to bridge the complex science-policy interface?

Agricultural research has had its goals shifted over the years as the country's ideologies and interests are metamorphosed. Efforts to meet food security goals may have weakened inherent adaptation of agricultural systems. Agroforestry extension and research have neither survived the negative impacts of competition from other land uses nor overcome partners' and farmers' perceptions of what it can or cannot offer for climate change adaptation. Climate and agricultural research rarely synergize to include the decision-makers within each sector (CGIAR, 2008). Interested and affected groups have rarely looked at the mitigation and adaptation to climate change from inside out. Lessons and experiences of communities who have coped with climate variability have largely been ignored. National level initiatives are driven by collective action at the international level. Subsequently, local level mainstreaming initiatives are top-down and rarely evidence-based. At the national level, addressing climate change mitigation and adaptation is impeded by the challenges associated with links between knowledge systems and action domains. Understanding these links is fundamental to climate change adaptation. The way power relations translate into initiatives aimed at addressing climate change vis-à-vis the dynamics of climate change at national levels shape institutional adaptation.

Given this background, we oppose the business-as-usual approach, and promote mainstreaming of climate change adaptation. This is achieved through an understanding of the political economy of climate change, institutional adaptation, disconnects between climate change modeling and action. Also of equal importance is the understanding of the implications of nesting climate change adaptation in different policy domains and drawing on the subsidiarity principle to enhance functionality. We argue for a solid evidence base for taming climate change which can only be achieved if its future relevance and current gaps are re-examined by the users of agricultural research outputs and the science-policy interface.

Contextualizing climate change

Christensen *et al.* (2007) summarizes the key attributes of the Intergovernmental Panel on Climate Change's IPCC's Fourth Assessment Report for Africa as follows: (i) warming is very likely to be larger than the global annual mean warming throughout the continent and in all seasons, with drier subtropical regions warming more than the moister tropics; (ii) annual rainfall is likely to decrease in much of Mediterranean Africa and the northern Sahara, with a greater likelihood of decreasing rainfall as the Mediterranean coast is approached, (iii) rainfall in the southern Africa region is likely to decrease in much of the winter rainfall regions and western margins, (iv) there is likely to be an increase in annual mean rainfall in East Africa, and (v) it is unclear how rainfall in the Sahel, the Guinean coast and the southern Sahara will evolve.

The precarious food situation prevailing in most of southern Africa has been linked to a combination of factors including: unfavourable climatic conditions (Kandji *et al.,* 2006), poor and depleted soils (Akinnifesi *et al.,* 2008), environmental degradation, and macro-economic and political factors. There is a rapid rate of forest land disappearance and degradation, Pinstrup-Anderson *et al.* (1997) estimated that 664,000 ha of forest land were deforested in 1980s compared with just 92,000 ha of reforestation.

Mendelsohn *et al.,* (2000) observed that agriculture losses in some areas of the Sahara were between 2 and 7 % of the gross domestic product (GDP); 2 to 4% in Western and Central Africa; and 0.4 to 1.3% in western and southern Africa. In Ethiopia, ENSO related conditions have been attributed to declining maize production in the southern African region (Stige *et al.,* 2006). Maize production has been observed to decline in the southern African region. Drought is estimated to have caused 10 to 50 yield losses on 80% of the area planted to maize in southern

Africa (Short and Edmeades, 1991, as cited by Kandji *et al.,* 2006). In addition to less than optimal food production, dry season fodder shortage has also exacerbated the food insecurity problem in the region (Kandji *et al.,* 2006; Chakeredza *et al.,* 2007).

Factors that are likely to complicate efforts to combat climate change include: (i) a 0.4 global overshoot of human's Ecological Footprint is estimated at 7.1 acres per person (www.RedefiningProgress.org), (ii) declining of Africa's bio-capacity, (iii) an increase in the number of countries with human development index (HDI) of less than 0.5 (UNDP, 2005), (iv) population increase, (v) stresses on health and well-being, (vi) heavy reliance on highly climate sensitive sectors, (vii) high poverty levels, and (viii) structural related factors, such as policy failures and corruption. Climate change as a threat multiplier will potentially worsen the existing scenario, although positive impacts will exist as a result of increased rainfall, including increased productivity in the arid and semi-arid areas.

Africa's poor level of bio-capacity is attributed to relatively low levels of economic activity, lack of technologies and imports of bio-capacity. The continent receives imports of crop land and pastures land capacity through trade, and supplies other regions of the world with products from fishing grounds and forests (Swiss Agency for Development and Cooperation and Global Footprint Network, 2006). Such exchanges of bio-capacity are likely to drive exhaustion of productive areas and enhance the impacts of climate change. South Africa's bio-capacity is declining fast because it is pursuing development pathways which have been termed risky despite improvement of its people's living standards. Increased food and timber demands are driving conversion of tropical rainforests into agricultural land, and therefore, releasing aboveground carbon to the atmosphere.

Climate change is likely to disrupt African economies because they are natural resource dependent. Critical watershed and biodiversity areas have been converted to agricultural use to meet local and international demand for agricultural produce as well as energy requirements at different levels. The increases in population lead to increased pressure on the natural resources. Urbanizing environments and their associated demand for agricultural products drive land use change further afield as adjacent agricultural land is converted into commercial and industrial use.

Perceptions of the approaches currently pursued, including afforestation, off-setting, clean development mechanisms (CDM) and REDD programmes vis-à-vis short-term interests of African nations, and by extension, local communities, are likely to falter gains already made. Mitigation and adaptation measures have been observed to weaken already existing coping mechanisms. High poverty levels drive new investments and initiatives that are likely to have perverse incentives (e.g., farmers cutting trees to plant new ones to access carbon financing) for climate change mitigation and adaptation. Mainstreaming climate change is a resource intensive activity. Given the high levels of poverty, corruption, and divergent interests, transaction costs, challenges associated with matching climate change 'dynamism' with institutional innovations, mainstreaming may not be treated as a priority for the African continent. Mechanisms to quantify uncertainties and potential impacts of such initiatives are just picking up now.

Shifts in the policy arena, with or without exogenous influences, will shape emission rates. As countries adopt new long-term sectoral based economic planning blueprints (e.g., Kenya's Vision, 2030) drifts towards ecological deficits and increased carbon footprints will be obvious.

Parallel mechanisms to deal with adverse outcomes of paradigm shifts are not integrated into economic planning and development. Less resource endowed countries that are already funding mainstreamed programs, such as in Malawi, from their exchequer are confronting challenges associated with permanence, leakage, property rights (tenure of sequestered carbon), additionality and resource constraints (Michael Richards, 2008). Countries that previously allocated more than 10 per cent of their national budget for agricultural development as per the Maputo Declaration are slowly sliding (FAO, 2008).

Impacts of climate variability are already constraining the capacity of local communities to meet their requirements. Kandji and Verchot (2007) provide an overview of impacts and responses to climate variability at local, regional and national levels. These impacts are likely to be worsened by climate change (FAO, 2007) if adaptation mechanisms are not mainstreamed. Questions abound as to whether African governments should pursue climate change mitigation or adaptation? What is clear in the literature is the none exclusivity of mitigation and adaptation, but there are controversies on carbon neutrality, carbon offsetting, afforestation/reforestation and REDD programmes that have differently influenced Africa's position on the climate change debate.

Climate change action in Africa

Sub-Saharan Africa and climate change adaptation

Adaptive capacity is driven by the totality of resources available (natural, human, financial and social), governance, technological advancement and planning practices, many of which still remain weak in the African continent (UNFCCC, 2008). However, through various funds from the UNFCCC, about 24 countries in sub-Saharan Africa have completed National Adaptation Programmes of Action (NAPA). So far, little has been done in terms of the implementation of adaptation priorities identified in the NAPA's for most countries. Most adaptation action is done by a few projects that operate on a more sub-regional basis. Examples include: (i) the Climate Change Adaptation in Africa Program (CCAA) run by IDRC and DFID working in more than 10 countries, (ii) Tropical Forests and Climate Change Adaptation Project (TROFFCA) in West Africa, (iii) GEF funded projects to assist African communities to assess risks and options to adapt to drought, coastal flooding and health risks, such as Coping with Drought and Climate Change (in Mozambique, Zimbabwe and Ethiopia), (iv) Adaptation to Climate and Coastal Change in West Africa (ACCC) (in Senegal, Cape Verde, Guinea Bissau, Gambia and Mauritania), and (v) Adaptation to Climate Change in eastern and southern Africa (ACCESA) - Kenya, Mozambique and Rwanda. Little evidence exists about proactive country actions on adaptation to climate change.

Sub-Saharan Africa and climate change mitigation

Current rules within the Kyoto Protocol of the UNFCCC allows developing country participation in climate change mitigation through the Clean Development Mechanism (CDM). The CDM makes provision for investment by industrialised countries and industry, in projects related to carbon reduction and carbon sequestration in the energy and forestry sectors in developing countries. These projects should contribute to sustainable development in developing countries (non-Annex 1 Countries) while enabling developed countries (i.e., Annex 1 Countries with quantified emission reduction targets) to meet the Kyoto emission reduction and quantified limitation targets (Art 12 of the Kyoto Protocol).

African countries are seriously lagging behind in the development of projects within CDM. As of May 2008, African countries had only 5% of the more than 3000 CDM projects at different stages in the pipeline (CDM Pipeline website). Reasons advanced for the poor performance of Africa have included, overly regulated CDM procedures, poor investment climate in Africa (financial, managerial, political), lack of capacity and poor governance for the inertia in the development of CDM project in Africa (Desanker, 2005, Minang 2007, Capoor and Ambrosi, 2006; 2008; and Walker *et al.,* 2008). The fact that only afforestation and reforestation projects are eligible for CDM projects has been an important limiting factor for forestry projects as a whole.

However, about 50 Land Use, Land Use Change and Forestry (LULUCF) related projects have been identified in Africa (Jindal *et al.,* 2008; Walker *et al.,* 2008). Most of these projects are likely to serve the voluntary carbon markets where the regulations are less demanding.

Recent developments during the 13th Conference of the Parties to the UNFCCC in Bali, Indonesia offer new hope for better opportunities for Africa's participation through a potential Reducing Emissions from Deforestation and Degradation (REDD) framework in a Post 2012 Climate Framework. Current REDD proposals allow the possibility for including avoided deforestation and forest management activities. This means more specific activities in these countries could be eligible compared to on afforestation and reforestation activities that are presently eligible within the CDM. The Bali Road Map sets out a two-year process to determine the modalities for a post 2012 climate agreement including for REDD (Decision-CP 13). The negotiations so far have seen very active participation of African countries, much more than have been registered to date. A case in point is the Congo Basin Group that have made submissions and actively participated in the debates as well as other African countries that have also participated in the negotiations through the Rain Forest Coalition. The best current proposals for REDD point to national level or sub-national level rather than project level accounting, hence comparatively high capacity and governance challenges beyond the project scale. It also raises challenges of equitable distribution of any benefits from REDD to local level, and also land rights issues at multiple levels.

What is the role of agricultural systems in climate change mitigation in Africa?

Agriculture is Africa's most important economic activity as most of the inhabitants of the continent depend on it for a living, yet it is one sector that is likely to be hard hit by climate change. Temperature increases and rainfall changes are expected to reduce yields from rain-fed agriculture by up to 50 % by 2020, and net revenues from crop yields could drop by as much as 90 % by 2100. Semi-arid and arid areas in Africa are projected to increase by between 5-8 % by 2080, and between 75 and 250 million people are projected to be exposed to an increase in water stress by 2025, hence profoundly affecting agriculture in these areas (IPCC, Fourth Assessment Report, 2007). These threats and the current effects of rainfall variability already felt by African farmers make a compelling case for putting agriculture at the centre of climate change adaptation in Africa. In addition, the conversion of forest land for agricultural purposes accounts for a significant proportion of Africa's GHG emissions (though very low).

Agroforestry constitutes one agricultural system with tremendous potential for climate change adaptation and mitigation in Africa. The introduction of innovative tree-based production practices into farming systems could improve resilience to inter-annual variability in rainfall and temperature, simultaneously contributing to climate change mitigation through carbon sequestration. Diversifying production systems to include significant tree components can enhance productivity of higher value tree crops and products which may buffer against income risks associated with climatic variability. First, tree-based systems enhance resilience and adaptation to climate change due to obvious advantages for maintaining production during wetter and drier years. Their deep root systems are able to explore a larger soil volume for water and nutrients, which help during droughts. Second, increased soil porosity, reduced runoff and increased soil cover lead to increased water infiltration and retention in the soil profile which can reduce moisture stress during low rainfall years (Verchot *et al.,* 2007).

Agro-ecosystems and agro-forests play an important role in global carbon cycles, holding about 12% of the world's terrestrial carbon (Dixon, 1995). Verchot *et al.* (2007) estimate the carbon mitigation potential of agro-forestry to be above 6000 Mt CO_2 e over a 30 year period. Research within the Alternatives to Slash and Burn (ASB) Partnership for Tropical Forest Margins on agroforestry systems, such as jungle rubber system in Sumatra, pine–banana–coffee system in eastern Java and Indonesia, mixed cocoa and fruit tree plantations in Cameroon contain between 50 to 75 Mg C ha^{-1} compared to row crops that contain < 10 Mg C ha^{-1} (Palm *et al.,* 2005). Thus, converting row crops or pastures to agro-forestry systems can greatly enhance the C stored in above-ground biomass.

Despite these potentials, several obstacles remain in the development of tree based systems that can serve poverty alleviation purposes, increase resilience to climate change and sequester carbon. One of these challenges is the lack of knowledge, skills and information.

Agricultural education and research

Climate change is causing, and will continue to cause, important changes in African agriculture. Farmers will need to react to these changes by adjusting their farming practices, crop varieties, cropping calendars, and minimization strategies, among many other changes. Over time, these changes will pose increasing challenges to agricultural research and extension as their competence to deliver appropriate services to the farming communities (under the changing scenarios) may become compromised by limited knowledge. Agricultural educational institutions need to react pro- actively to this challenge by ensuring that their agricultural graduates are well trained to appreciate and to be able to deal appropriately with the effects of climate change in the field. What are the key challenges for educational institutions and curriculum developers to re-tooling old graduates who are already out there in the field? Some of the reactions to make agricultural education remain relevant to the realities of climate change on farmers' fields may include revising, re-structuring and/or enlarging the educational curriculum to include topics on "climate change and African agriculture", and an understanding of the existing coping and adaptive strategies by local communities in different geographical locations.

Agriculturalists rarely interact with climatologists because of their nature of training. Climate change is neither the traditional mandate of meteorological services, nor agriculturalists. In whose realm does climate change lie? How is it handled by several sectors and how do the sectors interact with each other? The failure of African governments to adequately deal with these questions creates some confusion among institutions responsible for training in agricultural education. Consequently, mitigation and adaptation interventions are developed at levels that are not operational. Agricultural decision makers fail to make the right decisions because of the inability of agricultural technocrats to offer strategic advice. In some instance, there is overemphasis on the impacts and multiplier effects of climate variability because they are perceived as real. Despite increased collective action and awareness at the international level and looming threat of climate change, national-level institutional adaptation or innovations do not match the 'dynamism' of climate change. African governments are at different levels of putting in place appropriate institutional frameworks for dealing with climate change mitigation and adaptation at regional and national levels.

The Stockholm Environment Institute (2008) undertook an inventory of institutions and programs active in African climate science and agricultural education and concluded that: (i) there is lack of comprehensive baseline information; (ii) the impacts of climate change are isolated from the broader contexts in which development takes place; (iii) institutions adopt adaptation mandates without clearly understanding the vulnerability context; (iv) failure to conceptualize adaptation in the context of the other climate information used in decision making, and `(v) there are disconnects between information producers and users. According to SEI (2008), most research is driven by international institutions, with some already investing in boosting the robustness of their supported projects to climate change impacts. These challenges were further expounded and re-emphasized during the CGIAR Drivers of Change Workshop held from June 12-13, 2008 at the International Livestock Research Institute (ILRI) in Nairobi, Kenya. During the workshop, links between international research institutes, and the focus on national interest by national agricultural research systems were explored. Availability of good historical data was seen as critical in understanding the dynamics of climate change, its impacts on agricultural systems and depicted dynamics are likely to shape the future. During the CGIAR workshop, some of the salient research elements that emerged as critical for climate change research included the following:

Answering the right questions. Most of the simple problems have been solved except the complex ones which require more integrative approaches. However, the right questions must be raised with the right people. Perhaps agricultural and climate research have been asking and solving the wrong questions, at least from the perspective of national agricultural research systems. This could be attributed to the failure of international institutions to influence policy processes because of poor linkage of research results with national interests or science-policy communication disconnect. Agricultural education graduates are also not prepared to deal with emerging challenges including climate change. Education institutions seldom review their curriculum on climate change. The best that exists is climate change integrated into traditional courses in tertiary institutions. Science-policy linkages continued to evade scientists in the region. Many commentators, including the Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN) attribute this to the failure of scientists to package their science information in a manner that can attract the interests of agricultural policy makers.

Despite increased awareness on climate change and the flow of research funds, there are disconnects between modelling and what is most practically needed. In some places there is historical data but not used to predict huge climate uncertainty because of lack of collaboration between the Meteorological and Hydrological Services with the Ministry of Agriculture and agricultural policy makers. Meteorological Services Departments often produce data as an income generating activity. More cross-sectoral coordination is warranted to improve the current scenario.

Linking climate change research to the broader context. Broader issues of agriculture often hide the importance of climate change at farmer or national level. Research undertaken in Machakos, Kenya by ICRISAT indicated that farmers attributed declining crop productivity to climate change, but when ICRISAT analyzed other factors from a broader context, declining crop productivity was linked to declining trends in the use of fertilizers (CGIAR, 2008). Rainfall trends were established to have remained constant over the years. This is because of government's policy rather than climate change. In Malawi, the heavy attention to the fertilizer subsidy programme as a way of improving crop productivity may have obscured the need for attention on climate change in the short-term when the rains have also been satisfactory. This supports SEI (2008) argument that adaptation initiatives require the understanding of the vulnerability context.

Doing science from inside out. Scientists often ignore lessons and experiences that local communities have gained over the years as they adapt to the impacts of climate variability. ICRISAT's research on adoption of new crop varieties in the Sahel shows that farmers eagerly adopt new crop varieties but over time they discard them and go back to their traditional crop varieties (CGIAR, 2008). Further research showed that the traditional varieties were more adopted than those developed and promoted by the scientists. The same is true in Malawi for local open pollinated maize versus improved dent maize varieties. Building on existing coping and adaptive strategies of local communities is therefore important. It is prudent to see climate change as an integrative science requiring integrating both local and scientific knowledge with local circumstances. However, this also calls for proper needs assessment in the development and promotion of new technologies.

Dialogue. The World Agroforestry Centre (ICRAF) has tried to address this challenge through the design and adoption of negotiation support systems in southeast Asia for the purposes of linking knowledge systems to action. Negotiation support systems are now being expanded to Africa through ICRAF's work on compensation and rewards for environmental services currently being tested in different agricultural landscapes across Africa.

Community of practice. Platforms for sharing lessons and experiences are lacking. National and regional platforms will provide lessons for learning and act as springboards for country-based or collective action for climate change. Through these platforms, there will be review of adaptation initiatives, methodologies, tools and approaches. Existing platforms should re-look at their focus and expand their agendas to include climate change mitigation and adaptation.

Agricultural and climate science research at the national level are compartmentalized, segmented and rarely promote synergies and collaboration. The use of research results and data at the national level are complicated by monocentric governance systems with distributed regime structures and excessive red tape. Disconnects between science-based evidence and policy implementation at different levels are lacking because policy implementation are left to the discretion of technocrats at different levels. Mainstreaming of adaptation in country policies, plans and programmes need to learn lessons and be informed by science-based evidence.

Agroforestry research and education

Over the years, the World Agroforestry Centre (ICRAF) and its partners have developed approaches, tools and methodologies on how to quantify carbon, its potential impacts and landscape-level measurement and monitoring of carbon stocks (Kandji *et al.,* 2007; Verchot, 2007; ICRAF, 2006; Lusiana *et al.,* 2007). Apart from training university students, ICRAF facilitates and supports curricula development and reviews to shape universities' contributions to the pool of knowledge of emerging large-scale environmental and development challenges, including climate change. Despite these efforts, evidence-based decision making is scanty just as research and research results are scattered and uncoordinated. International agricultural and climate science research institutions, government research institutes, universities, private sector, and advocacy institutions are compartmentalized, segmented and operate as independent entities. Meteorological Services Departments have reduced their roles to producing and selling data. Agricultural research is focused on how to improve agricultural productivity in different agro-ecological zones.

Research institutes expect the same advocacy institutions to use the generated knowledge to shape policy, their interests withstanding. Scientists have attributed weak linkages between science and policy to their failure to appropriately package research results and create demand for their outputs. It is not so much about the lack of knowledge on climate change, but how best generated knowledge can be used to catalyze change, in this case climate change adaptation. It is much more about understanding and framing use of knowledge by action institutions. In order to promote 'knowledge to action' and 'action to knowledge' in different domains, three questions become relevant: what type of relevant agroforestry education exists in Africa? What are the gaps? What can be done to promote synergy 'knowledge to action' and 'action to knowledge?'

Relevant agro-forestry education

In Africa, the agro-forestry research-development-education continuum has slowly been evolving. Agro-forestry research is broad and multi-disciplinary. It brings together different disciplines and expertise, including foresters, environmentalists, economists, educationists, climatologists, agriculturalists, hydrologists, GIS analysts and policy experts. International institutions have adopted a two track approach in addressing multi-disciplinarity in agroforestry research: deliberately employing scientists with different expertise to ensure that these experts are in-house or source for expertise through exchange programs or collaborate with other institutions to fill any identified gaps. In the region, the focus has mainly been on climate science in the hope that this informs agricultural research and development. Climate science research is externally driven and those involved report based on donor requirements and rarely promote policy changes. When funding for a specific project ends, the project ceases and the research outputs are forgotten. A review by SEI (2008) shows that regional research institutions lack resources, undertake macro-level analysis with limited understandings of local level phenomena; not focused on specific issues that agricultural policy makers are interested in; and much of the work is focused on gaining atmospheric dynamics which are important strategically but not of interest to farmers.

Relevant agroforestry research and training in African universities is influenced by historical, structural, perceptive and the objectives of education. Curricula of many African universities established during the colonial period have not been reviewed over the years and where review has been done; it has been mainly piecemeal (Ngugi *et al.,* 2002). The general trend is that newly established universities offer nothing different from what is offered by universities established during the colonial period. Forestry education, agricultural and climate related science education offered in African universities are patterned and shaped after models that were already in place in Europe and North America (Temu and Kiwia, 2008). Temu and Kiwia (2008) further argue that agricultural science and related degree programmes focus more on biophysical aspects as a means to an end, which is mainly improving productivity of agriculture. No room was created for broader agricultural training that would prepare the governed for self-sustenance (Temu *et al*., 2003). Who have also recognized the need to promote multi-disciplinarity and curricular reviews, such as integrating natural resource management and entrepreneurship in tertiary agricultural education.

An in-depth analysis of the courses offered by newly established universities does not reveal a shift, including integration of emerging large-scale environmental problems. Since climate change is an emerging issue, it is not adequately integrated in universities' existing curricula. It is limited by the segmented and entity based nature of university curricula. 'Traditional' and emerging degree programs are broad and deal with bits and pieces of climate change and agroforestry. Subjects that are relevant to climate change science are rarely offered in universities, and many experts in the region have learnt through on-the-job training in international funded research institutes. Structural factors that limit training on emerging issues include: (i) inadequate funding, (ii) lack of laboratories and equipment, and (iii) lack of expertise and poor lesson learning and experience sharing between universities and international institutes that are undertaking cutting-age research.

There has been general decline in the number of students being admitted into mainstream agricultural degree programs. This has been attributed to lack of job opportunities. Students take particular courses that would be easy to secure well-paying jobs. Such decline in the level of expertise in agricultural science is a major constraint to innovations in the sector and will affect food security in the long run. There are ongoing initiatives to promote revitalization of agricultural and agro-forestry education and research. These initiatives will potentially be affected by lack of frameworks and approaches to translate 'knowledge into action' and 'action into knowledge'.

'Knowledge to action' versus 'action to knowledge'

Meine (2008) has framed 'knowledge to action' or 'action to knowledge', using the concept of boundary organization. Meine's framework however needs to be understood within the context of multi-layered regime structures and how they are either influenced or influence regional and international level policy domains. In linking action to knowledge and vice versa, Meine identifies large international assessment efforts, such as the Inter-government Panel on Climate Change (IPCC) and the Millennium Ecosystem Assessment (MEA) (Figure 30.1).

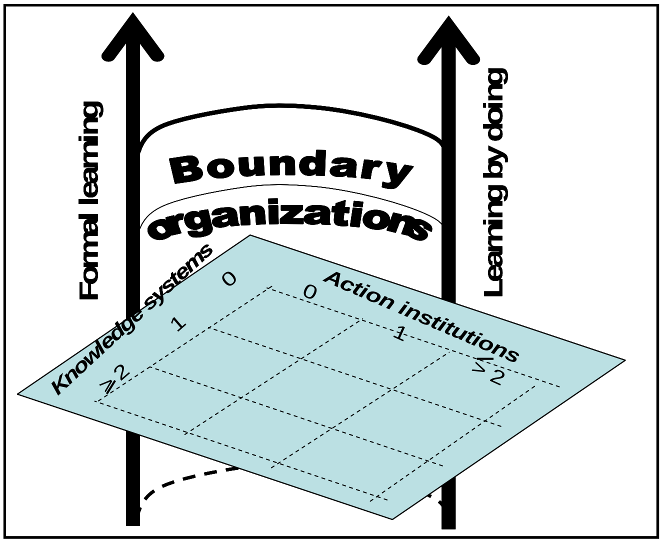

Figure 30.1: Typology of boundary organizations on the interface of knowledge and action, with examples of six classes of boundary work

Based on Figure 30.1, Meine (2008) and the University of Arizona (2000) developed typologies of boundary organizations based on a 0, 1 and □2 classification of actors and ways of knowing (Table 30.1). Six classes have been identified as follows:

1. 0. A ⬄ A, no K, meaning not informed by any since;
2. I. K ⬄ K, no A, knowledge not influencing any action;
3. II. K ⬄ A -- the archetypal boundary work of technology transfer, science-policy advice, public funding for science and decision support systems; the IPCC effort falls within this class with its ‘policy relevant’ but not ‘prescriptive’ synthesis of science
4. III. K ⬄ (A ⬄ A) -- boundary work, such as ‘joint fact finding’ that can emerge `at a certain stage in (mediated) political negotiations
5. IV. (K ⬄ K) ⬄ A – integrated assessments, such as the Millennium Ecosystem Assessment (MEA)
6. V. (K ⬄ K) ⬄ (A ⬄ A) – negotiation support systems and the emerging reward mechanisms for environmental systems, where both the articulation of knowledge and the actions are negotiated

Table 30.1: Typology of boundary organizations on the interface of knowledge and action, with examples of six classes of boundary work

---------------Action------------------

-----Knowledge-----

	0. None	1. Decision	⩾2 Collective action
0. Conjecture & ignorance	*Daily life of U&Me ☺*	A (ignorant decisions)	0 $A_1 \Leftrightarrow A_2$ (ignorant politics)
1. One truth	K (science, Knowledge for own sake)	II $K \Leftrightarrow A$ (Technology Transfer; Scientific policy advice such as IPCC; Decision Support Systems - DSS)	III $K \Leftrightarrow A_1 \Updownarrow A_2$ (Joint fact-finding)
⩾2 Multiple ways of knowing	$K_1 \Leftrightarrow K_2$ I (Interdiscipli-narity, tacit + scientific knowledge)	IV $K_1 \Updownarrow K_2 \Leftrightarrow A$ (Integrated Assessments such as MEA)	V $K_1 \Updownarrow K_2 \Leftrightarrow A_1 \Updownarrow A_2$ (Negotiation Support Systems - NSS, RUPES)

In order to effectively promote ‘knowledge to action’ or ‘action to knowledge’, the six classes of boundary spanning activities must be understood in the contexts of feedbacks, strong or weak, across the different multilevel regime structures. Within each level, there are sector-based policy domains (in this paper we have used agriculture, forestry, energy, water and wildlife), which relate with climate change adaptation in different ways, a relationship that is limited by vertical planning and governance systems pursued by different African institutions.

The national level sub-unit is charged with policy formulation and implementation facilitation. Lower level sub-units are mainly responsible for translating policy provisions into actions with lessons and experiences feeding into the national level policy formulation sub-unit. In the case of climate change, national level lessons and experiences feed into regional and international level negotiations and decisions. Policy, plans, projects and programmes implementation at different regime structure levels are often not informed by research undertaken by different organizations at different levels. Implementation of policies, plans, projects and programmes is also affected by the complexities associated with multilevel governance systems (Figure 30.2). Regional-level initiatives influence and are shaped by what is happening at the national-level domain. Discussions at the international level on several policy areas and collective learning and action initiatives influence what is happening at the national and country-level domains. International level negotiations and collective action are also influenced by what is happening at the regional and national levels. Climate change adaptation or any other large-scale environmental problems are then nested in the different levels of governance providing opportunities of learning lessons across different levels.

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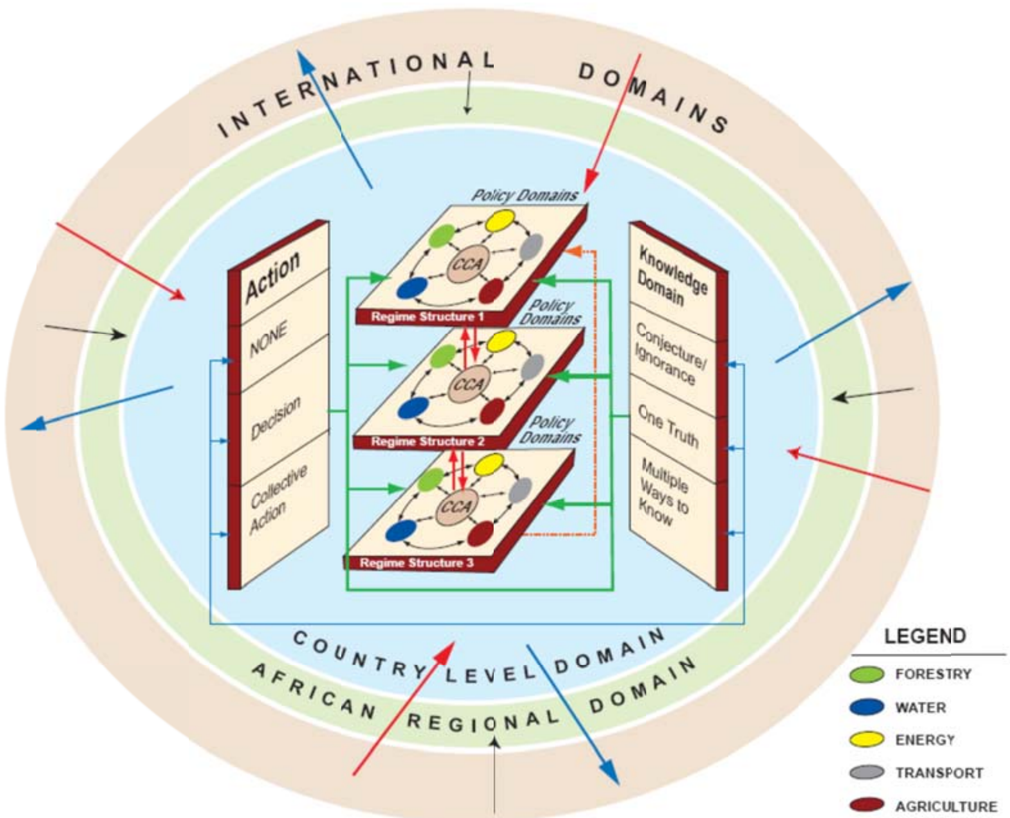

Figure 30.2: Relationships between different domains and how nested climate change adaptation (CCA) could be addressed through interactions between action institutions and knowledge systems (Adapted from Yatich *et al*. (unpublished and undated).

Challenges, opportunities, gaps and the way forward

Positioning agricultural and agro-forestry education to address climate change will require an integrated approach, including strategic policy development, cross-sectoral policy formulation, implementation, coordination and institutional adaptation. Lack of strategic policy formulation to deal with emerging threats of climate change is likely to heighten its impacts at various levels. Mainstreaming climate change adaptation is a challenge in the face of differing mandates of different sectors and power relations that shape feedback mechanisms. It will take time for the advantages of cross-sectoral policy frameworks to be achieved because reviews of legal regimes in Africa are long, tedious, bureaucratic and jingoistic. There is need to explore opportunities to deal with challenges related to sectoral policy planning and its implications for climate change adaptation and mitigation in Africa.

Decentralization and devolution provide opportunities for climate change mitigation and adaptation and also find expression in numerous legal instruments. In most countries, the tendency is to move away from more or less exclusive state competencies to stronger management responsibilities and property rights in local governments and communities. Ongoing initiatives could provide lessons and experiences for refocusing and restructuring agricultural education and agro-forestry. The economic and institutional reforms in African economies have however created constraints and opportunities for climate change adaptation. Reed (2004) enumerates these opportunities as the dismantling of state-controlled marketing systems, the removal of bureaucratic obstacles to initiating small-scale enterprises, the opening of market outlets for new crops and products, and the opening of some political structures to public participation. The institutional reforms have also created constraints for the poor: entrenchment of political and economic elites, new resource management regimes that preclude access for the poor, decentralization reforms that shift power to regional power brokers but not to the poor, and increased vulnerability to economic shocks that threaten the meager asset base of the rural poor (Reed, 2004). These constraints do not prepare the poor to adapt to climate change or promote interventions at the strategic level to boost the resilience of agricultural systems against impacts of climate change.

There is need, therefore, to promote integrative science and match research outputs with national level interests. The universities core activities are teaching and knowledge generation, research and community service. In order to promote the sharing of tools, approaches and methodologies, universities need to build synergies in the implementation of their mandates. It is only through this that collective action and learning among tertiary institutions can be enhanced. Government based institutions, universities and regional/international research institutes need to work together to find strategies for influencing policy at different levels because: (i) they generate knowledge that is relevant for policy change, and (ii) are interested in achieving change. Leveraging resources to achieve the desired use of research results to influence policy will require networking and understanding, the outcomes of the interactions between action and knowledge domains.

Conclusion

Disconnects between action research and policy practices are attributable to the failure to correctly identify boundary spanning activities. Complexity of governance systems and feedback mechanisms between multilevel regime structures affect the implementation of large-scale environmental programme, climate change inclusive. Interventions aimed at addressing large-scale environmental problems, such as climate change adaptation, are further complicated by the quality of Tertiary Agricultural Education (TAE), which tend to operate as independent entities. This is further reflected in the public sector where different policy domains are sector-based and operate independently. Action research is externally driven and often does not inform policy formulation and implementation, but contribute to a knowledge system that can be tapped into by action institutions to influence policy. Such potential is limited by divergent interests of institutions expected to have demand for solid evidence for policy influence. Providing a framework for identifying boundary spanning activities and how these can shape or be shaped by interactions among different multilevel regime structures would be the first step in addressing climate change mitigation and adaptation. Such a framework will also heighten the need for curricula review in tertiary institutions so as to promote synergy and coordination of training in the different agriculture related disciplines. The proposed framework will also promote evidence-based decision making to deal with the challenges of climate change adaptation.

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31. Science Teachers' Perceptions on Introducing Climate Change Education in Secondary and Primary Schools Curricula in Malawi

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Abstract

There is a common tendency to neglect involving the youth in addressing global concerns. Climate change must not be one of them. Climate change is an attempt to mitigate the harmful effects of human practice on the environment so as to preserve it for our children and there is no better way to do so than to involve the youth in that process. This paper, therefore, takes a pragmatic approach to addressing the problem of climate change. It argues for introducing climate change education in secondary and primary schools. This study of secondary school teachers is one piece of evidence advanced for this contention. Do secondary school teachers feel climate change is an issue important enough to be introduced in the curriculum? If so, what capacity building training as they need to offer this curriculum? A survey of secondary school science teachers in the Lilongwe city conducted this month, just in time for this conference, revealed that secondary school teachers support climate change education one hundred percent. They say that this is an important issue, which must be addressed now and not left to our children. More than that, they feel it should be included in the curriculum and express a need for capacity building to help them teach it. The limitation of the study is that the sample size was very small. We, therefore, recommend a national study to determine if our findings hold true. For, if it does, it is a major expression of the need for the Government to take on the issue. We feel that inculcating in the youth a culture of environmentalism, is the key to building sustainable ecological stewardship. It will also show-case Malawi as a leader in promoting ecology-based food security education.

Key words: Youth, Climate change, primary schools, secondary schools

Introduction

Malawi, like many other Sub-Saharan African countries, faces a multitude of social, economic and environmental problems that are attributable to global warming or climate change. These include changing rainfall patterns, rising temperatures and the drying up of rivers, to name just a few. At the heart of the problem is increasing degradation of farmland and increasing poverty and the challenge of meeting the food security needs of the country. Beyond the traditionally held categorization of climate change as an environmental issue, it is clearly also a development issue: poverty reduction, food security, economic, health, human rights, governance and equality. It is an MDG issue.

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This paper argues that climate change strategies, like development, if they are to be sustainable, must be embraced by the entire population. It cannot be something imposed from the top. Secondly, the paper argues that climate change, for the most part is concerned about the future, that is our youth and the generations yet unborn. Thus, we further contend that if climate change strategies are to be sustainable, then the youth must be involved. After all, it is their world that is at stake and what better way to preserve and protect the future than to involve them in the process?

Thus, our paper is an attempt to find a strategy for dealing with climate change. In particular we focus on the youth as a sub-population that must help address the issue of climate change. We are exploring the possibility of including climate change education in the curriculum of secondary and primary schools in Malawi. We feel that if this idea is to take hold, the science teachers in secondary and primary schools are the ones who will be asked to shoulder the bulk of the task. Thus, we contend that a strategic approach is to determine the readiness of these teachers to promote climate change education.

We are still exploring the idea including a discussion with the Ministry of Education, Science and Technology. However, to strengthen our case to the Ministry, we felt a quick survey of a small group of teachers will help make our case. For example, do these teachers think climate change is an issue we should be concerned about, let alone introduce it as a curriculum in the schools? Thus, the paper is a report of a survey on the perceptions of secondary school teachers on climate change, the perceived causes, what can be done about it and whether it should be introduced in our schools.

Problem Statement

For African countries attention to climate change is no longer a policy option but a necessity. This is because there is overwhelming evidence that the risks of inaction or delayed action on climate change are so great as to be spelling our own doom. Stern and Noble (2008) contend that the world risks damages on a scale larger than the two world wars of the twentieth century, if it did nothing about climate change. They note that the threat is particularly alarming for the world's poorest people as inadequate responses to climate change would threaten progress on all fronts of the Millennium Development Goals.

The impact of climate change will be severest, the experts say, on countries in the tropics, with those in Africa most at risk. The *Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report* realized in 2007 notes that Africa is one of the most vulnerable regions because of its high dependence on rain-fed agriculture and limited financial capacity to pay for high food prices and human capacity to adapt to these changes.

The problem of climate change can be blamed in part on industrialized countries that cause damage to the atmosphere by emitting greenhouse gases, that is, through industrial pollution. While these countries must lead the way in solving the problem of climate change, the developing countries are equally to blame for the problem, on another front—deforestation and land degradation. For example, these factors account for 15 – 20 percent of the greenhouse emissions and will require donor funding of $15-20 billion a year to reduce the damage due to deforestation by half (Stern and Noble, 2008). Beyond the traditionally held categorization of climate change as an environmental issue, it is clearly also a development issue: poverty reduction, food security, economic, health, human rights, governance and equality. It is an MDG issue!

Climate change issues in Malawi

Malawi, in the last few years, has shown tremendous efforts at improving the living conditions of its people. Clearly, a lot more needs to be done but it goes without saying that the food security situation in Malawi today is much more improved that it was a decade or so ago. The Government's fertilizer subsidy program, among other measures has helped increased food production substantially and, thus, has curbed massive hunger in the country. Nevertheless, it is quite clear that the country still faces a multitude of social, economic and environmental problems that are threatening to deepen its dependency on foreign assistance.

The heart of the problem is the nation's high population, estimated at 12 million, which must depend on a small, restricted land area of only 9.4 million hectares. Malawi's development problems are exacerbated by frequently recurring droughts and floods leading to poor crop and livestock yields and worsening poverty, particularly in the rural communities (National Adaptability Program of Action, 2006). According to this report, those who tended to be affected most by the consequences of climate change are women and children.

To attain food self-sufficiency, alleviate chronic poverty and arrest environmental degradation concerted efforts are required by all stakeholders to enhance adaptation to climate change. There is strong scientific evidence that global climate may have already started changing in response to greenhouse gas emissions (IPCC, 2007). One of the most important conclusions of the IPCC is that "the balance of evidence suggests that there is a discernible human influence on climate." Analysis of Malawi's rainfall and temperature data show high rainfall variability in recent years (GOM, 2001) and variability in rainfall departure times during the last four decades (1959-1993) as shown in Figure 31.1.

Global mean surface air temperature has increased by 0.3 to 0.6 over the last 100 years (see also IPCC 1995). The temperature change scenarios generated by climate change models for selected agro-ecological zones for the years 2020, 2075 and 2100 show general increases in mean temperature by up to 1^0C by the year 2020, 2^0C by the year 2075 and 4^0C by the year 2100 (GoM, 2008). In general, the predictions for Malawi reflect what Hulme (1995) defined as an 'Aridification Scenario', or the 'dry' and 'core' scenarios; increased temperatures and decreased rainfall.

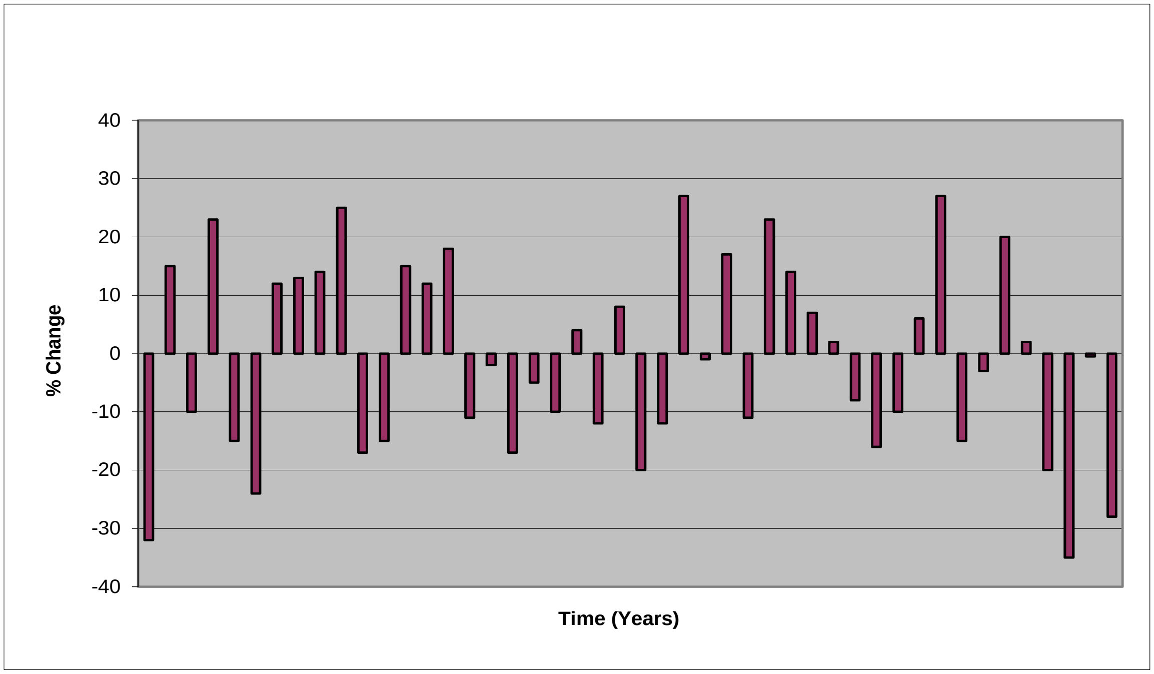

Figure 31.1: Rainfall departure times for Malawi (1949-1994)

Impact of climate change on crop and livestock production

The predicted maize grain yields from the three climate change scenarios used by GOM (2008) exhibit a fluctuating trend over time, principally in response to changing total rainfall over a 30-year period. In other areas, such as, Salima and Lilongwe the models predict high maize yields while in Thyolo they predict lower yields. In general, it can be concluded that changes in precipitation and temperature will lead to a decline in maize yield.

However, in the temperate zone experiments with maize varieties, such as, CGCM1-TR, ECHAM4 and HadCm2 (GOM, 2001) indicate a reduction of up to 500 kg per hectare in maize yields. Although the yield reductions or increments appear slight, they become quite considerable considering that 1.2 million hectares of maize are cultivated in Malawi. This translates to a yield reduction or increase of about 300,000 tonnes depending on the actual outcome.

The effect of climate change on livestock production is mostly related to impacts on rangeland and the productivity of animal feeds. Climate change is expected to enhance the direction of rangeland changes in three categories: a) the extension of bare soil as concentric circles around villages or drinking points associated with woodland thinning and depletion of grazing land; b) development of woody weeds that are not palatable to animals; and c) an increase in range fragmentation.

In addition to the crop and livestock production impacts, there are biophysical and socio-economic problems of global warming and climate change to worry about at the local, regional and national levels. The problem of managing water resources for crop and livestock production, recreation and other forms of livelihood will most likely be curtailed.

Local communities will most likely be faced with water related problems, such as, loss of fishing and vegetable gardening as means of livelihood. The current human resource base for Malawi has no capacity to understand these problems and there is need to undertake the proposed project for effective communication of climate change issues to Malawians in general and the youth in particular.

Rationale

Much of Africa's underdevelopment is often the result of lack of foresight or creative thinking, that is, the capacity to foresee and take appropriate action to forestall an-anticipated problems even before they occur. One such problem is the tendency to think that the solution to climate change lies in getting Government to legislate, that is, pass laws on a series of "don'ts." Clearly, some laws may be necessary but we also see an alternative approach—a positive way of giving people an opportunity to do something for the environment through voluntary action.

In particular, we think the youth is one audience that can easily get enthusiastic about doing something for the environment and in the process embracing it as a life-long mission. The United Nations Children's Fund (UNICEF) has stressed the important role the youth can play on global issues. For example, UNICEF has noted the need to actively involve children and youth in schools, community action, media and governance based on a recognition of children's and youth citizenship and their rights.

According to UNICEF, the youth needs to be involved in addressing key themes at the top of the G8 agenda, such as global warming, global health issues (HIV/AIDS, for example) and development in Africa. This is because all these issues affect children acutely; hence the direct involvement of children is critical.

The failure to involve Malawi's youth in its agriculture is evident in the lack of interest on the part of the majority of the country's youth to enter the agricultural profession. Malawi, with its lush climate and rich soil is well suited for agriculture, which is central to the country's economy and national life. Agriculture employs 86 percent of its workforce, and makes up 38 percent of its Gross Domestic Product (DGP) and 90 percent of its export earnings. Yet, the youth is hardly attracted to agriculture. The result is that in spite of the high unemployment rate in the country, over 30 percent of positions in the Ministry of Agriculture and Food Security goes unfilled (World Bank, 2008).).

We don't think the same should happen with climate change education. Clearly, it is unethical and probably immoral, for this generation to do nothing and leave those yet unborn to suffer the consequences of climate change. Similarly, it will be a grievous mistake not to involve the youth in seeking solutions to the environmental crises because they have a stake in it and the sooner we can involve them the better our chances of success.

Nangia (2008), acting vice president of the World Bank Institute, has noted that the challenges of climate change are broad based and a collaborative effort on the part of so many stakeholders, such as donor agencies, NGOs, governments, civil society and farmers is needed to mitigate its impacts. To this list we add the youth, whose very survival depends on it.

There this nothing better that our generation can do to guarantee the future safety of our youth than to involve them as stewards of the land. They need to understand the dynamics and complexities of the global environment, why there is hunger in Africa, why the continent is "boiling", and why the great lakes, such as Lake Chad, are trying up. They need to learn how to save their world from a looming catastrophe. All countries, whether developed or developing, has this educational task of communicating with our youth on climate change. This is a challenge and responsibility Malawi readily accepts and seeks to do something about it.

Common sayings like: "A stitch in time saves nine" and "To strike the nail while it's hot" point to the importance of proactive investment in educating our youth about the importance of climate change. The IPCC Report (2007) notes that mitigating the potential impacts of climate change is urgent and vital and requires action on all fronts, and that includes educating the youth. The school is a major forum for socializing the youth on important issues that affect them, such as HIV and AIDS, democracy, and climate change.

There are numerous other benefits in educating the youth in climate change. First and foremost, the future is their world and what better way to safeguard their survival than to engage them in discussions on climate change and how to protect, preserve and use this world in an ecologically sound manner.

Second, in rural areas in Africa, Malawi included, the youth is an active part of the farming enterprise. Even school children take turns to relieve their siblings in herding the cattle, sheep and goats during weekends. They also help in crop production and other household duties, such as fetching water and fuel wood. Therefore, the environmental and agricultural education lessons they learn from school can be directly applied in the field. Indirectly, they can also educate their siblings, parents, friends and neighbours about what they learn at school.

Third, today's youth are tomorrow's leaders—policymakers, scientists, technological inventors, business managers and commercial farmers. By inculcating in the youth, love for the environment we are preparing them to be good stewards of their ecological systems when they take their rightful places as tomorrow's leaders. Indeed, there is no better way to ensure future global unity than to introduce climate change education in all schools throughout the world. For, they will gather at world forums with a common purpose—to protect the global environment as changes in one part most likely affects the other.

Purpose and Objectives

The main purpose of this study was to determine whether secondary science teachers feel it is important to introduce climate change education in secondary and primary schools as a way of inculcating in our youth a spirit of environmentalism.

Objective

1. To describe the demographic characteristics of secondary school teachers vis-a-vis climate change education. For example, how much do they know about climate change?
2. To assess the perceptions of secondary school teachers regarding introducing climate change education in the curriculum. For example, are they for or against it?
3. To examine the capacity of secondary schoolteachers to offer climate change education. Do they feel capable or will they need assistance, in terms of capacity building or enhancement?
4. To assess constraints to introducing a curriculum on climate change education.
5. To identify secondary school science teachers' sources of information on climate change.
6. To examine correlations on secondary school teachers' perceived attitude towards climate change.

Methodology

This was a quantitative study using survey methodology. The population consisted of science teachers in secondary schools in the metropolitan Lilongwe area of Malawi. Lilongwe City, the capital of Malawi. There are eleven secondary schools in Lilongwe scattered within peri-urban area, with six of them in the city limits. These are: Bwaila, Chipasula, Dzenza, St. Jones, Lilongwe Girls, and SOS. There are also five secondary schools in the peri-urban area, namely: Likuni Boys, Likuni Girls, Chinsapo, Mitundu and Namitete.

In the interest of time, we picked five schools: Chipasula, St. Jones, Lilongwe Girls, SOS, and Mitundu, of which, four were urban and one, peri-urban. Again, due to time limitations, there was no effort made to include community day secondary schools. Only government and mission schools, for the most part, were included. The schools selected were institutions, which had existed for 15 years or more and we felt they were representative of secondary schools in the area. Table 31.1 shows the schools represented in the study.

Table 31.1: Schools represented in the study

School	Frequency	Percent
St. Johns	4	18.2
SOS	2	9.1
Li Girls	6	27.3
Chipasula	5	22.7
Mitundu	5	22.7
Total	**22**	**100.0**

Of the 11 government and missionary secondary schools in the Lilongwe metropolitan area, five were selected for the study. Only a convenient sample was used and there was no attempt to randomize the selection. Also, primate secondary schools were not included.

A questionnaire was developed by the researchers and face and content and validity checked by a panel of experts, who included environmental and agricultural educators at Bunda College and teachers at a secondary and primary school. In the process, ambiguous questions were rendered less ambiguous and more reliable. Reliability was improved by raising the number of questions per objective. However, no attempt was made to overwhelm respondents with unnecessary questions. Due to time limitations we did not include focus group discussion and key informant interviews in the study.

The study population consisted of science teachers. However, we did not know how many science teachers were in each school and, therefore, had to rely on the head teachers and head mistresses to assist us. We simply handed each head master or mistress, five questionnaires and instructed them to make more copies if there were more than five science teachers in the school. Of the 25 questionnaires distributed, 22 were completed and returned in usable form.

The 22 completed surveys were entered into an SPSS Mac 16.0 and analyzed. Univariate and bivariate statistics, such as frequency distribution, cross-tabulations, and measures of central tendency (the mean, median and mode) were calculated. Also analyzed were measures of spread, such as the standard deviation and range. Still yet, other advanced statistical analysis, such as comparing means of two groups, t-tests, and Pearson's correlation coefficient were calculated and reported.

Findings and Discussions

What follows is a presentation of the findings backed by a discussion.

Demographic characteristics of secondary school teachers

The purpose of this objective was to examine the profile of science teachers vis-a-vis climate change education. This is because climate change is a sophisticated interdisciplinary science and, therefore, to understand and deal with climate change issues, it would seem, would require well-trained teachers. The demographic characteristics examined included gender, age, level of education and others. Table 31.2 shows the gender composition of the respondents.

Table 31.2: Gender of respondents

Gender	Number	Percentage
Male	16	72.7%
Female	6	27.3%
Total	22	100.0%

Both male and female teachers were represented in the study. However, the female teachers represented about a third of the population. However, it was difficult to determine whether this proportion is a general reflection of the science teacher population.

The study also examined whether participants were married, or single. We found that 6 (27.3 percent) respondents were single and 16 (72.3 percent) were married. However, it did not appear that marital status had any effect on respondents' views. For example, respondents were unanimous that climate change is a problem that must be addressed.

With respect to age, there was an even spread. Six respondents (27.3 percent) were aged 30 yrs or less; nine (40.9 percent) were aged, 31 – 40 yrs; and seven (31.8 percent) were aged 41 and over. Again, it does not appear that age was a factor in the respondent's views.

Table 31.3: Number of children

Number of Children	Respondents	Percentage
No children	8	36.4
2 children	4	18.2
5 children	9	40.9
6 – 10 children	1	4.5
Total	22	100.0

Respondents were asked to indicate the number of children they had. Table 31.3 presents the results. Eight respondents (36.4 percent) indicated having no children; four (18.2 percent) had 1 – 2 children; 9 (40.9 percent) had 3 – 5 children; and 1 (4.5 percent) indicated having 6-10 children. Malawi as a whole, has a generally high number of children per family and this study seems to reflect this trend.

Table 31.4 reflects the educational status of respondents. By Malawi standards, the teachers were generally well educated as they all met the minimum standard and many of them exceeded it. The minimum standard is the Malawi School Certificate of Education (MSCE) and only two respondents (9.1 percent) of respondents carried this certificate. The next highest was the Certificate of Education, completed by two respondents (9.1 percent). Over 80 percent of respondents had higher qualifications, such as the Diploma in Education, the Bachelor’s Degree in Education (BED) and the Bachelor of Science Degree.

Table 31.4: Educational status

Type of Education/Qualifications held	Respondents	Percentage
Diploma in Education	9	40.9
BED (Bachelor’s degree in Education)	6	27.3
B. Sc.	3	13.6
Certificate of Education	2	9.1
JCE/MSCE	2	9.1
Total	**22**	**100.0**

Respondents were also asked to indicate their years of teaching experience. The data showed that six (27.3 percent) had 16 yrs or more years of experience; nine (40.9 percent) had 6 – 15 yrs; and seven (1.8 percent) had 5 yrs or less. Generally, it would seem that the teachers had a great deal of experience as over 70 percent of them had at least six years of experience.

Perceptions on climate change education

The purpose of this objective was to determine the perceptions of respondents on climate change. For example, have they ever heard of it, if so, when? What do they feel the public must do about climate change, and so forth. The overwhelming majority, 21 or (95.1 percent) had ever heard about global warming/climate change. Also, a substantially large number 15 or 68.2 percent, said they heard about it 5 or more years ago while only three (13.6 percent) said they heard of it only 2 – 3 yrs ago and the remaining four (18.2 percent) heard of it a year ago or less. In general, many respondents were aware of climate change.

They unanimously agreed that climate change was occurring. In Table 31.5, they were asked to indicate if the following signs of climate change were common, very common or extremely common in their areas. All respondents agreed that rivers were drying up, followed by deforestation (19 or 86.3 per cent of respondents). Soil erosion, high population growth and density, unreliable rainfall and bush burning, ranked in that order.

Table 31.5. Indicators of climate change

Indicators	Respondents	Percentage
Rivers drying up.	22	100.0
Deforestation	19	86.3
Soil erosion.	18	81.9
High population growth and density.	17	77.3
Unreliable rainfall.	17	77.3
Bush burning.	16	72.7
Loss of biodiversity	16	72.7
Industrial pollution.	14	63.6
Overgrazing	13	59.0

There was also a general agreement that the problem of climate change should not be left to future generations to solve. Nineteen respondents (86.4 percent) said it should not be left to future generations to solve while only three (13.6 percent) said it should be left to future generations to worry about.

Capacity to offer climate change education

Respondents were asked if they would need assistance in terms of capacity building to teach climate change education. Eighteen or 81.8 percent expressed interest whereas three or 31.6 percent said they would not need further training.

Science teachers were also asked to indicate what topics could be taught in secondary and primary schools as a part of climate change education. A Likert-scale was established for each statement, that is, ranging from Very Strongly Disagree (VSD), Strongly Disagree (SD), Disagree (D), Agree (A), Strongly Agree (SA) and Very Strongly Agree (VSA). Thus, the Mean Score (X=6.0) for each item. Table 31.6 shows that respondents were strongly agreed on the topics that needed to be taught. Standard deviation scores of less than 1.0 indicate the strength of agreement among respondents. There were very strongly agreements that climate change, water harvesting and agroforestry topics should be taught as a part of climate change. Although not a topic of climate change, Item #9 asked whether science teachers would welcome assistance from Bunda College students in their classrooms to assist in teaching climate change courses. There was unanimous agreement although there was a high degree of variation in the consistency of responses (SD=1.386).

Table 31.6. Level of agreement on climate change topics to be taught

Topic	N	X	SD
Global warming and climate change	22	5.68	.567
Water-harvesting technology.	22	5.68	.647
Agroforestry.	22	5.55	.671
Preserving the forest and wildlife, such as having a school forest.	22	5.36	.789
The green revolution, such as need for school gardens.	22	5.36	.789
Energy needs of the country.	22	5.20	.922
Children as teachers, teaching parents climate change	22	5.40	.848
Protecting biodiversity	22	5.30	1.393
I will welcome Bunda College students helping teach Environmental and agricultural topics to the children.	22	5.30	1.386
Ecosystem and land stewardship	19	86.40	1.478

Considerations to introducing a curriculum on climate change

Under this objective, respondents were asked to indicate constraints to introducing a curriculum on climate change education; give examples of materials they would use to teach children on climate change; agricultural and natural resources topics they currently teach in schools and so forth. The following were the findings.

a. Constraints to teaching climate change

Many items were mentioned as constraints to teaching a curriculum on climate change. The constraints covered mainly three areas: lack of educational materials, teachers' need for training; and students' lack of interest in science. More specific items listed were as follows: Lack of availability of teaching and learning resources; lack of educational visits by supervisors, inadequate teaching/learning materials; no motivation by the students in science due to bad background of students in science; laboratory apparatus are not enough, lack of teaching materials, such a s, books and the Internet; lack of chemicals; lack of refresher courses; most students consider it as difficult, hence lack of interest and attention; lack of interest by many female and some male students; lack of qualified teachers to teach the subjects; negative attitude on the part of students; lack of human resources (teachers); lack of in-service training; pupils' lack of interest; students not willing to learn; students' negative attitude towards science subjects; and lack of teaching and learning materials.

b. Examples of materials to use in teaching climate change

Teachers were asked to indicate what kinds of educational materials they would use to teach a course on climate change. The following were listed: The changing rainfall pattern and floods, which were not common in previous year; a refrigerator that emits CFC into the atmosphere;

carbon dioxide; water; abnormal high temperatures at certain times of the year; newspapers and other printed matter, including pictures of a flooding region, line graph showing increasing temperatures for a period of 10 years, records of annual rainfall changes, and books of proven scientific facts. Other items include scarcity of firewood, unreliable rainfalls and drought experienced, show them a film on the rate of drying up of the sea, and the local environment around the school; rain gauge, and thermometer; reports (radio, TV and newspapers) on climate change.

c. Agricultural and natural resources issues addressed in curriculum

The following topics were being addressed in a secondary school curriculum: Agriculture and the environment, agricultural technology, challenges in agricultural development, conservation of natural resources, ecosystem, photosynthesis, food security, population, nutrition, housing, living things and their environment, application of halogens and halogen components, environmental hazards associated with CFCs, ozone radioactive substances, national parks and game reserves, grazing of animals, desertification, natural resources and natural disasters.

d. Practical exercises science teachers do with their students on agricultural and natural resources.

These included planting of trees/plants as biological control of soil erosion; construction of contour ridges, box ridges and waterways in the school field; deforestation, teaching grazing and farming methods; establishment of a woodlot at the school; pasture establishment and conservation; observing types of erosion in our area; planting trees every year; protecting trees and grasses from fire; planting trees; establishing wildlife clubs; and use of CO_2 during photosynthesis.

e. Reasons for global warming

Reasons for global warming included: Greenhouse gases/Destruction of ozone layer due to industrial gases, deforestation, rapid population growth; bad farming practices, such as careless cutting down of trees and burning the bushes; illiteracy and drought.

f. Things that can be done to reduce climate change.

On things that can be done to reduce the speed of climate change the following were listed: Afforestation and re-afforestation, stop cultivating on steep slopes, avoiding the release of harmful gases, use of ozone friendly materials; avoid excessive production of gases, which destroy ozone layer; avoid deforestation; ban the use of devices that emit chlorofluorocarbons (CFC); pass legislation that should ban unnecessary cutting down of trees; bad farming methods, proper waste disposal from the factories; environmental education; intensive countrywide tree planting projects (multimillions), establishment of carbon sinks; avoid the use of chlorofluorocarbons, i. e., in the refrigerators; avoiding cultivating on river banks; using unleaded petrol; reducing the amount and level of pollution from industries; civic education to public; and using systems that release little CO_2 into the atmosphere.

g. Why students should learn about climate change

Teachers were convinced that students should learn about climate change for the following reasons: because it affects sustainable development--development that provides for the present and future needs; climate change will affect food production--the agricultural calendar and industry; children are the future and should know how to protect the environment; if children are taught issues of climate change they will take a leading role in preventing it; it is important that they know the effects and how they can be able to control/avoid them; and so that the knowledge about climate change is passed from one generation to the next. Other reasons included: Their awareness can help them take part in solving the problem now and in the future; they have to be schooled of what is happening around them so that they begin to take up challenges to address the problems; they should participate in conserving nature; they are the future teachers; and so that children will be able to manage their own environment with responsibility to avoid climate change.

Science teachers' sources of information on climate change

Respondents were asked to indicate their sources of information on climate change. Table 31.7 shows the results. Television appeared as the main source of information for 19 (86.4 percent) of respondents. Radio and newspapers came in second at 77.3 percent, mentioned by 17 respondents. This was followed by the Internet and "Family and Friends" a distant fifth.

Table 31.7: Sources of Information

Source	Respondents	Percentage
TV	19	86.4
Radio	17	77.3
Newspapers	17	77.3
Internet	9	40.9
Family and friends	7	31.8
Other specify	2	9.1

Note: Totals could exceed 100 percent because respondents were allowed to check more than one.

All respondents expressed interest in receiving information on climate change. However, only 18 out of the 22 or 81.8 percent indicated having access to computers. Still less, only 11 respondents (50.0 percent) had access to the Internet through Internet kiosks. Lastly, 14 or 63.6 percent of respondents indicates a need for training on how to use the computer or Internet.

Correlations on secondary school teachers' perceived attitude towards climate change

The study examined the relationships using the *correlation coefficient* or *Pearson's r*. Basically, what we wanted to know was whether a high score in one variable, such as "protecting biodiversity" is associated with a high score in another, such as " the need for a green revolution, namely, need for a school garden." Did respondents who scored high in one also score high in the other?

Correlations were run between selected climate change variables (Table 31.8). Based on Davis' (1971) conventions for describing magnitude of relationships, a significant, positive, very strong relationship was found between energy needs of the country and water harvesting technology (Pearson r = .796, p = < .01, n=22). Also, significant, positive, substantial associations were found between green revolution, need for school gardens and their belief that in water harvesting technology (Pearson r = .752, p = < .01, n=22); green revolution, need for school garden and children as climate change teachers (Pearson r = .718, p < .01, n=22); and a significant, positive and moderate relationship was found between energy needs of the country and protecting biodiversity (Pearson r = .571, p = < .01, n=22). There were also moderate, positive relationships

Table 31.8: Correlations of Correlations of secondary school teachers' perceptions on climate change

	1. Energy needs of the country	2. Protecting biodiversity	3. Green revolution, need for school gardens.	4. Ecosystem and land stewardship.	5. Global warming and climate change.	6. Water harvesting technology.	7. Children as climate change teachers.
1. Energy needs of the country	1.00	.571**	.535**	.319	-.236	.796**	.620**
2. Protecting biodiversity		1.00	.485**	.430*	.495*	.447**	.341
3. Green revolution, need for school gardens.	.		1.00	.1.000	.282*	.752**	.718**
4. Ecosystem and land stewardship.				1.00	.321*	.143	
5Global warming and climate change.					1.00	-.029	-.033
6. Water harvesting technology						1.00	.236*
7. Children as climate change teachers.							1.00

* p < 0.05 (two-tailed); ** p < 0.001 or .01 (two-tailed) between protecting biodiversity and ecosystem and land stewardship (Pearson r = .430, p = < .05, n=22); protecting biodiversity and global warming and climate change(Pearson r = .495, p = < .05, n=22).

Conclusions and Recommendations

This study set out to determine whether: a) there was interest among secondary school science teachers for climate change education; b) what resources will be needed to offer such a curriculum; c) teachers' views on why students need to learn about climate change; and d) the capacity building need of science teachers who will be asked to offer climate change education. The study found an overwhelming interest among teachers for climate change education. They gave many reasons why students need to learn about climate change, such as preparing them to take a leading role in preventing the problem; to pass on the knowledge for future generations;

and the fact that students have a right to know what is happening around them so that they begin to take up challenges to address the problems that face their world. The study also found that a curriculum on climate change education will have many benefits as revealed through the correlation coefficients of variables. For example, those who said involving children will help them to become educators of others also said that children will help green the environment.

From these findings, the following recommendations are made:
1. There is a need to replicate this study on a wider, national scale so that the findings can be generalizable to all secondary and primary school teachers in Malawi. This is necessary if the findings are to have policy implications.
2. We urge the Ministries of Education, Science and Technology; Agriculture and Food Security; Youth and Sports and Environmental Affairs to come together to examine the implications of the findings for an integrated approach to ecosystem sustainability, food security and education that addresses the nation's main economy—agriculture.
3. A study of secondary and primary students themselves is needed to better understand their knowledge of and interest in climate change. What climate change educational activities would excite them?
4. There is a need to take this educational program to the college or university level by developing, implementing and evaluating sustainability curricula, practices, and academic programs. College students can be innovative in developing new, environmentally-friendly energy sources. They are also more likely, than secondary and primary school students to assume national policy making decisions.
5. The Government needs to explore sources of funding, such as from international donors, to carry out a pilot project in this area. Our young people know the stakes and given the opportunity, they will take appropriate actions that will affect their lives, their economic well-being, and the planet they are inheriting.

By taking action to provide climate change education to the schools, Malawi will, perhaps, among the leading countries in the world in this regard. The US Congress has approved a grant to help universities undertake sustainable agricultural research and education. Congressman Earl Blumenauer (D-OR), one of the three original sponsors of the Higher Education Sustainability Act (HESA), part of the new Higher Education Opportunity Act of 2008 (HR 4137). HR 4137 (HESA), explained: "As the world's population increases, so does our impact on the environment, which makes it more vital than ever to invest in training the next generation of scientists, engineers, planners and business professionals."
The interrelationship between climate change and agricultural development in Malawi is clear. By investing in climate change education for the youth, we will be developing sustainability programs, protecting the planet, increasing agricultural growth, strengthening our global and economic competitiveness and contributing to the achievement of the Millennium Development Goals (MDGs). "

In short, sustainable economic development, environmental protection, and poverty reduction and social justice can all be realized if we incorporate climate change education in our schools.

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32. Enlarging and Updating Information and Knowledge in Sub-Saharan Africa: Mainstreaming Contemporary Issues in Climate Change into Agricultural and Renewable Natural Resources Education

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Abstract

It is incontrovertible that research and education (R and E) are necessary for growth and development. This has necessitated increased and sustained efforts aimed at encouraging various strategies for achieving benefits from it, particularly in the developed countries as against what obtains in the developing (under-developed) ones. The prevalent levels of under development in most of these countries particularly those in the sub-Saharan Africa (SSA) has been linked to inadequate and/or weak R and E which has resulted from various reasons. One of the global contemporary issues in which R and E is necessary is climate change (CC), traced mainly to anthropogenic sources. In SSA countries, majority of the inhabitants that are more populated in the rural areas, are dependent on agricultural and renewable natural resources (RNR) for their sustenance/livelihood. These resources are believed to be influenced and/or affected by the vagaries of CC in terms of regenerative and/or productive capabilities. Thus, there is no gainsaying that more studies/researches are necessary in this area, most especially in SSA where capacity building is still obviously needed. Many studies/researches concerning the causes and effects of CC including recommended mitigation/adaptation strategies and how to achieve them have been carried out and documented, mostly in the developed countries where capacities in terms of human, facilities and financial resources are comparatively more available, although, the bulk of CC precursors are produced in this part of the world. This article was therefore, aimed at reviewing published results of such studies/researches concerning effects of CC on agricultural/RNR, activities and products, mitigation/adaptation strategies and how to achieve them including necessity for incorporating these information into agricultural/RNR education with the overall aim of contributing to the efforts at increasing/updating information and knowledge base in R and E and the capacity for sustainable production and use of these agricultural and RNR in SSA.

Key words: Climate change, sub-Saharan Africa, renewable natural resources, agricultural research and education, growth and development

Introduction

Climate can be defined from different perspectives but in a narrow sense it is usually defined as the “average weather”, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate change (CC) refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). CC may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. CC, in Intergovernmental Panel on Climate Change (IPCC) usage, refers to any change in climate over time, whether due to natural variability or as a result of anthropogenic activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where CC refers to a change of climate that is attributed directly or indirectly to anthropogenic activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods (IPCC, 2001). The UNFCCC thus makes a distinction between "climate change" attributable to anthropogenic activities altering the atmospheric composition, and "climate variability" attributable to natural causes.

Outcomes of series of studies/researches have shown that only a limited number of factors are primarily responsible for most of the past episodes of CC on Earth. According to Anon (2007) these factors include variations in the Earth's orbital characteristics, volcanic eruptions, solar output and atmospheric carbon (IV) oxide (CO_2) including other greenhouse gases (GHG) like methane, nitrous oxides, fluorocarbons, among others. The variations in terms of continuous increase in the volume of these gases in the atmosphere has been intensified since industrial period of the 1800s (Friedli *et al.,* 1986; Hansen *et al.,* 1998; Ledley, 1999; Keeling and Whorf, 2006) with an increase of up to 70% between 1970 and 2004 (IPCC, 2007) and this has been projected to accelerate during the coming century (e.g. Houghton *et al.,* 2001; IPCC, 2007) with far-reaching negative consequences on the environment, which the sustainable agricultural and renewable natural resources (RNR) production are dependent on particularly in the developing countries (Erakhrumen, 2007a) and most especially those in the sub-Saharan Africa (SSA).

It is no more news that the survival of the inhabitants of many parts of SSA countries largely depends on sustainable generation and use of agricultural and RNR (Adger *et al.,* 2003; Sunderlin *et al.,* 2005; Thomas and Twyman, 2005; Ogunsanwo and Erakhrumen, 2006; Ulsrud and Eriksen, 2007) particularly the poor who are mostly living in the rural areas of this region (Canagarajah, 1998; Popoola and Akinwumi, 2001). Owing to the importance of these resources to the inhabitants of this region, vulnerable research and educational capacity there (Erakhrumen, 2007b) and the environmental factors influencing and/or affecting the sustainable production of these resources, there is need for sustained efforts through more studies/researches that will contribute to sustained increase regenerative and productive capacity of these resources with particular attention on climate, its changing pattern with time, causes and how these affect this capacity including how to mitigate and/or adapt to the effects.

In line with the above, this article is aimed at reviewing published results of studies/researches in this regard, particularly those conducted in the developed countries concerning effects of CC on agricultural/RNR activities and products, mitigation/adaptation strategies and how to achieve them including necessity for incorporating these information into agricultural and RNR education with the overall aim of contributing to the efforts at increasing/updating information and knowledge base in research and education (R and E) and capacity for sustainable production and use of these resources in developing countries, particularly in SSA.

Some effects of climate change on agriculture, renewable natural resources, activities and products

Documented outcome of series of studies/researches revealed that CC already/or will have a range of impacts on agricultural and RNR systems. For instance, vagaries in climate might lead to hotter seasons which will likely result in increased demands on scarce water resources with likely negative impacts on viability of some crops. CC might even support the spread and virulence of some pests and diseases with drastic negative consequence on farmland, livestock, crops, wildlife, landscape, soil and water resources apart from other effects on agricultural and RNR productivity. Increased intensity and frequency of storms, drought and flooding, altered hydrological cycles and precipitation variance have implications for future food availability. The potential impacts on rain-fed agriculture *vis-à-vis* irrigated systems are still not well understood (FAO, 2007). The developing world already contends with chronic food problems. CC presents yet another significant challenge to be met. While overall food production may not be threatened, those least able to cope will likely bear additional adverse impacts (WRI, 2005). The estimate for Africa is that 25-42 % of species habitats could be lost, affecting both food and non-food crops (FAO, 2007).

In developing countries, 11 % of arable land could be affected by CC, including a reduction of cereal production in up to 65 countries, about 16 % of agricultural GDP. Changes in ocean circulation patterns, such as the Atlantic conveyer belt, may affect fish populations and the aquatic food web as species seek conditions suitable for their lifecycle. Higher ocean acidity (resulting from CO_2 absorption from the atmosphere) could affect the marine environment through deficiency in calcium carbonate, affecting shelled organisms and coral reefs (FAO, 2007). Some studies have also predicted some short term scenarios with particular attention on agriculture and RNR, as quoted below, although it is noteworthy that the list is not exhaustive: (i) soil loss due to wind and water erosion; (ii) Decrease in soil quality as organic content, soil life and minerals are lost; (iii) extreme natural disasters (floods, landslides, earthquakes, etc.) will lead to erosion; (iv) increased frequency, intensity and unseasonal fires will damage soils and plants leading to alien plant invasion and wind erosion, (v) soil moisture will decrease due to loss of cover and accompanying loss of organic content in the soil, (vi) increased temperature and temperature extremes, (vii) degradation of natural zones leads to loss of environmental services such as soil formation, water retention and flood attenuation, pollinators and soil life, (viii) changed alien invasion patterns increase threat to biodiversity and productive potential;, (ix) erratic rainfall patterns leading to extreme droughts and rainfall events e.g. storms and floods, and (x) reduction in quantity and quality of groundwater and the recharge rate.

In line with the above and other points not stated, CC impacts can be roughly divided into two groups according to FAO (2007). These are: (i) **biophysical impacts** (physiological effects on crops, pasture, forests and livestock (quantity, quality, changes in land, soil and water resources (quantity, quality, increased weed and pest challenges, shifts in spatial and temporal distribution of impacts, sea level rise, changes to ocean salinity, and sea temperature rise causing fish to inhabit different ranges), and (ii) s**ocio-economic impacts** (decline in agricultural/RNRs yields and production, reduced marginal GDP from agriculture; fluctuations in world market prices; changes in geographical distribution of trade regimes; increased number of people at risk of hunger and food insecurity, and migration and civil unrest)

Climate change mitigation and adaptation, some suggested strategies and global agreements

Based on series of studies documented in the literature, most of the suggestions regarding mitigation of CC and strategies at achieving this have been aimed at reducing and or limiting the emissions of GHG into the atmosphere and the removal of toxic substances from the environment using various methods ranging from physical, mechanical, chemical, biological and combination of these processes (Poon, 1986; Jain and Tyagi, 1992; Periasamy and Namasivayam, 1994; Polprasert, Dan and Thayalakumaran, 1996; Adewuyi, 2001; Dietz and Schnoor, 2001; Schwartz *et al.,* 2001; Gogate, 2002; Rasmussen and Olsen, 2004; Erakhrumen, 2007a; Ruddell *et al.,* 2007). Series of adaptation strategies has also been recommended. Two approaches can be used simultaneously in achieving the above, bearing in mind that adaptation and mitigation issues often go hand in hand and should not be considered in isolation of each other by: (i) addressing the causes of CC either by reducing GHG emissions or by capturing and storing those emissions, and (ii) learning to adapt to the impacts brought by CC.

Adaptation to CC is the adjustment of practices, processes and structures to reduce the negative effects, particularly the unavoidable ones, and take advantage of any opportunities associated with CC. It is important to note that people differ in their vulnerability to the negative effects of CC because they differ in their livelihood strategies, social and political relations, and the types of stressors to which they are exposed, and they differ in their attempts and capacity to adapt to changing conditions. Mitigation involves human intervention in reducing the GHG emissions from energy and biological sources or enhancing the sinks of GHG. Key mitigation technologies and practices by selected sectors are tabulated in **Table 32.1** bearing in mind that change in lifestyle and behavioural patterns can contribute substantially to CC mitigation across all sectors.

Management practices can also have a positive role as stated below according to IPCC, (2007): (i) lifestyle changes can reduce GHG emissions. Changes in lifestyles and consumption patterns that emphasize resource conservation can contribute to developing a low-carbon economy that is both equitable and sustainable, (ii) education and training programmes can help overcome barriers to the market acceptance of energy efficiency, particularly in combination with other measures, (iii) changes in occupant behaviour, cultural patterns and consumer choice and use of technologies can result in considerable reduction in CO_2 emissions related to energy use in buildings, (iv) transport Demand Management, which includes urban planning (that can reduce the demand for travel) and provision of information and educational techniques (that can reduce car usage and lead to an efficient driving style) can support GHG mitigation, and (v) in industry, management tools that include staff training, reward systems, regular feedback, documentation of existing practices can help overcome industrial organization barriers, reduce energy use, and GHG emissions. In the opinion of IPCC (2007), a wide variety of national policies and instruments are available to governments to create the incentives for mitigation action. Their applicability depends on national circumstances and an understanding of their interactions, but experience from implementation in various countries and sectors shows there are advantages and disadvantages for any given instrument as stated in **Table 32.2**. **Table 32.3** shows summary of some practical examples of how CC adaptation can add to development and poverty eradication efforts. Four main criteria are used to evaluate policies and instruments. These are: (i) environmental effectiveness, (ii) cost effectiveness, (iii) distributional effects, including equity, and (iv) institutional feasibility.

Table 32.1: Selected mitigation technologies and practices by sector

Sector	Key mitigation technologies and practices currently commercially available	Key mitigation technologies and practices projected to be commercialized before 2030
Energy supply	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind, geothermal and bioenergy); combined heat and power; early applications of Carbon Capture and Storage (CCS, e.g. storage of removed CO_2 from natural gas)	CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and waves energy, concentrating solar, and solar PV
Transport	More fuel efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land-use and transport planning	Second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries
Buildings	Efficient lighting and delighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation ; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycle of fluorinated gases	Integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar PV integrated in buildings
Industry	More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non-CO_2 gas emissions; and a wide array of process-specific technologies	Advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture
Agriculture	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH_4 emissions; improved nitrogen fertilizer application techniques to reduce N_2O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency	Improvements of crops yields
Forestry/forests	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use	Tree species improvement to increase biomass productivity and carbon sequestration. Improved remote sensing technologies for analysis of vegetation/ soil carbon sequestration potential and mapping land use change
Waste Management	Landfill methane recovery; waste incineration with energy recovery; composting of organic waste; controlled waste water treatment; recycling and waste minimization	Bio-covers and bio filters to optimize CH_4 oxidation

Table 32.2: Selected sectoral policies, measures and instruments aimed at achieving mitigation technologies including some constraints or opportunities

Sector	Policies, measures and instruments shown to be environmentally effective	Key constraints or opportunities
Energy supply	Reduction of fossil fuel subsidies Taxes or carbon charges on fossil fuels	Resistance by vested interests may make them difficult to implement
	Feed-in tariffs for renewable energy technologies; Renewable energy obligations; Producer subsidies	May be appropriate to create markets for low emissions technologies
Transport	Mandatory fuel economy, biofuel blending and CO_2 standards for road transport	Partial coverage of vehicle fleet may limit effectiveness
	Taxes on vehicle purchase, registration, use and motor fuels, road and parking pricing	Effectiveness may drop with higher incomes
	Influence mobility needs through land use regulations, and infrastructure planning Investment in attractive public transport facilities and non-motorised forms of transport	Particularly appropriate for countries that are building up their transportation systems
Buildings	Appliance standards and labelling Building codes and certification Demand-side management programmes Public sector leadership programmes, including procurement Incentives for energy service companies (ESCOs)	Periodic revision of standards needed Attractive for new buildings. Enforcement can be difficult Need for regulations so that utilities may profit Government purchasing can expand demand for energy efficient Products Success factor: Access to third party financing
Industry	Provision of benchmark information Performance standards Subsidies, tax credits	May be appropriate to stimulate technology uptake. Stability of national policy important in view of international competitiveness
	Tradable permits	Predictable allocation mechanisms and stable price signals important for investments
	Voluntary agreements	Success factors include: clear targets, a baseline scenario, third party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry
Agriculture	Financial incentives and regulations for improved land management, maintaining soil carbon content, efficient use of fertilizers and irrigation	May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation
Forestry/ Forests	Financial incentives (national and international) to increase forest area, to reduce deforestation, and to maintain and manage forests	Constraints include lack of investment capital and land tenure issues. Can help poverty alleviation
	Land use regulation and enforcement	
Waste management	Financial incentives for improved waste and wastewater management	May stimulate technology diffusion
	Renewable energy incentives or obligations	Local availability of low-cost fuel
	Waste management regulations	Most effectively applied at national level with enforcement strategies

Table 32.3: Summary of some practical examples of how CC adaptation can add to development and poverty eradication efforts

Challenges weakening poor people's adaptation Strategies	**Measures that may contribute to both adaptation and poverty reduction**
1) Development interventions inadequately taking account of poor peoples' livelihoods and adaptation strategies • Imposition of external technologies, such as large scale water dams, spreading of 'modernized' farming systems and seeds and exotic tree species into arid environments • Underutilisation of knowledge accumulated from adaptation to local climate conditions • Little research infrastructure and support for adapted production systems such as nomadic pastoralism and indigenous tree products • Isolated and large-scale infrastructure provision projects such as irrigation neglecting other pressing needs, especially those of the poor • Forced relocation of people in informal city settlements, pushing poor city dwellers to peripheral areas away from livelihood options	Measures to strengthen poor people's livelihood and adaptation strategies • Support and develop local technologies, including shallow wells, sub-surface dams, water harvesting techniques, local seed varieties and planting of indigenous tree species. Support marketing of local products • Document past and present adaptation strategies and supplement them with relevant strategies and technologies, support local knowledge systems • Facilitate improvements of production systems adapted to normal climate stress, like pastoralism and indigenous tree products, through strengthening marketing infrastructure, veterinary services, research and development, processing and value adding. • Evaluate how infrastructure provision may affect the climate change vulnerability of the poor, ensure poor people's needs, for example water access for adaptation strategies • Improve drainage systems and flooding protection in low-income areas, avoid relocation if possible and ensure continued access to livelihoods. Cooperate with the inhabitants on infrastructure and house improvements or if necessary, on relocation.
2) Consequences of degraded ecosystems for Vulnerability • Lost potential for the use of ecosystem products and services for economic and social development • Lack of innovative use of ecosystem services and neglect of the importance of forest products in adapting to climate variability and change • Lack of access to existing and relevant knowledge and technologies, one-sided focus on Conventional, centralised energy supply	Climate change adaptation through improved and innovative management and use of local ecosystems • Maintain and strengthen ecosystems, improve access for poor people. Emphasise community management and access to protected areas and counteract privatisation and large scale commercial exploitation of crucial adaptation resources, such as water or forest. • Strengthen people's opportunities for both traditional and new ways of taking advantage of ecosystem services. Clarify land tenure and land use rights. Promote raw materials like Jatropha and other hardy biofuel crops and local collection and processing. • Facilitate the use of environmental technologies, including agro-forestry, organic farming techniques like mulching and planting of cover crops, harvest local resources like solar power, surplus biomass, wind and geothermal energy

3) Barriers hindering poor people's adaptation Strategies	Measures for removing structural and regulatory Barriers
• Lack of attention to the income sources of poor people	• Provide facts about the economic importance of income generating activities performed by the poor. Facilitate south-south transfer of experiences
• Income generating activities during drought such as charcoal limited by the ambiguous legal framework, which siphons profits away from the poor producers, discourages investment and encourages unsustainable practices	• Change the poor legal structures of the sector, promote efficient kilns for charcoal burning, promote sustainable practices of wood harvesting and growing.
• Discourses labelling adaptation strategies of the poor as unsustainable or primitive	• Uncover myths and exaggerations, identify underlying reasons for unsustainable practices, invest in research and development of livelihood and adaptation strategies based on local resources
• Little value adding to natural products and poor market position of products. Lack of infrastructure for transportation and information exchange adapted to the needs of the poor	• Support small-scale processing plants products. Improve transport facilities (trains, buses, roads planned for cycles, carts and pedestrians) and other factors to access markets, provide relevant and timely market information.
• Marginalisation of nomadic pastoralism and barriers to migration	• Ensuring access to drought grazing areas, facilitating migration and seasonal trade through providing security and infrastructure (like water points, markets, roads, and health and veterinary services)
• Poor health limiting household labour and engaging in adaptation strategies	• Measures to reduce the incidence of malaria among the poor, enhanced health systems, make treatment for HIV/AIDS available to the poor
• Conflicts and insecurity leading to loss of lives and productive assets and making access to key resources for adaptation, such as drought grazing, unsafe	• Strengthen police posts and security in marginal areas, enhance conflict resolution and civil society such as peace committees

Source: Ulsrud and Eriksen, (2007)

It is important to note that all instruments can be designed well or poorly, and be stringent or lax. In addition, monitoring to improve implementation is an important issue for all instruments. Forests and forestry has been identified as being central to issues relating to environmental sustainability. Forests can also be employed in promoting CC mitigation owing to their ability to remove CO_2 from the atmosphere with the aim of stabilizing CO_2 concentrations in the atmosphere. Some actions which can be taken in the forest sector to achieve this according to Patosaari (2007) are: (i) managing forests with high carbon uptake potential, (ii) expanding such forests through reforestation and afforestation, (iii) reducing deforestation and reversing the loss of forest cover, (v) providing an enabling environment for investments and market access to sustainable forest-based products, and (vi) increasing the use of forest-based products such as bio-energy and durable wood products, and substituting these for less eco-efficient materials.

In order to achieve the objective of mitigating the effects of CC, series of protocols, conventions, and agreements on CC has also been adopted by many countries, some of which, (e.g. the Kyoto Protocol) major polluters like the United States has refused to be part of, perhaps there is no chance that the US will make their 7 % reduction of GHG emission over 1990 levels target.

Some of these protocols, conventions and agreements are: (i) **Montreal Protocol: t**he Montreal Protocol on Substances that Deplete the Ozone Layer was adopted in Montreal in 1987, and subsequently adjusted and amended in London (1990), Copenhagen (1992), Vienna (1995), Montreal (1997) and Beijing (1999). It controls the consumption and production of chlorine- and bromine-containing chemicals that destroy stratospheric ozone, such as CFCs, methyl chloroform, carbon tetrachloride, and many others (IPCC, undated), (ii) **United Nations Framework Convention on Climate Change (UNFCCC): t**he Convention was adopted on 9 May 1992 in New York and signed at the1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community. Its ultimate objective is the "stabilisation of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". It contains commitments for all Parties. Under the Convention, Parties included in Annex I aim to return GHG emissions not controlled by the Montreal Protocol to 1990 levels by the year 2000. The convention entered into force in March 1994 (IPCC, undated), (iii) **Kyoto Protocol: t**he Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was adopted at the Third Session of the Conference of the Parties (COP) to the UNFCCC, in 1997 in Kyoto, Japan.

It contains legally binding commitments, in addition to those included in the UNFCCC. Countries included in Annex B of the Protocol (most OECD countries and countries with economies in transition) agreed to reduce their anthropogenic GHG emissions (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) by at least 5% below 1990 levels in the commitment period 2008 to 2012. The Kyoto Protocol has not yet entered into force (IPCC, undated), and (iv) **Bali Action Plan (BAP):** in order to help in securing the best possible framework to replace the Kyoto Protocol by 2012, the UK Department for International Development (DFID) is working with other government departments. In December 2007, the Parties to the UNFCCC agreed the Bali Action Plan. This sets out the key elements of a new framework and a roadmap for agreeing them by 2009. DFID want to ensure this agreement minimises the impacts of CC on developing countries by setting a goal of stabilising GHGs in the atmosphere at a level which avoids dangerous CC.

Adaptation of forest to climate change and its role in mitigation efforts

Considering the above submissions and others in the literature, it will be clearly observed that discussions on CC have focused disproportionately on mitigation and adaptation using various strategies including forest and other phytomass, e.g., for carbon sequestration. Trees, soil and forests take in carbon at a rate that is determined by a number of factors including the type of forest, its location, and its age. Forests store large amounts of carbon in trees, under-story vegetation, and soil. IPCC, (2007) estimates that about 65% of the total mitigation potential in the forest sector is located in the tropics and about 50% of this total could be achieved by reducing deforestation. Generally speaking, young, growing and well managed forests are good "sinks".

Tropical forests are able to take-in and store carbon at a greater rate than boreal forests although, not all forests are good carbon "sinks." Old-growth forests may be net-emitters of carbon as the large proportion of older trees begin to decompose. Nonetheless, human activity in the form of deforestation and forest degradation are the primary drivers of carbon emissions from forests. It has been estimated that tropical deforestation accounts for about 20% of human-generated CO_2 emissions (House *et al.,* 2006), although, the overall figures still require much further clarification.

Forest management and forest operations have a long term effect on human-generated emissions, and all the factors contributing to the balance between emissions and storage are not yet fully understood (Patosaari, 2007). Nevertheless, much less emphasis has been placed on how management activities might help tropical forest ecosystems itself adapt to CC in order to maintain the provision of goods and services to society (Guariguata *et al.,* 2007) although, in many countries CC is perceived as a relatively minor threat to forests compared with socio-economically driven causes of land-use change such as pasture expansion, illegal logging, or otherwise uncontrolled forest conversion (Lambin *et al.,* 2001). These management activities are necessary because of the critical role of tropical forests as globally significant standing stocks of above- and below ground carbon (Dixon *et al.,* 1994) and also because atmospheric carbon sequestration through tree planting is the only currently eligible land use change activity for developing countries within the Clean Development Mechanism (CDM) of the UNFCCC for which there is an international carbon market and where Certified Emission Reductions are traded (Guariguata *et al.,* 2007). Climate change adaptation in tropical forestry will be necessary because forest-related mitigation activities often have a cost advantage over other mitigation strategies. They can also be designed to support other national development and poverty alleviation priorities because of the multiple benefits forests provide. Tropical forests make important contributions to rural livelihoods (Sunderlin *et al.,* 2005; Patosaari, 2007) and, partly because of this, natural resource users in developing countries are frequently considered highly vulnerable to CC (Adger *et al.,* 2003; Thomas and Twyman, 2005).

The enhancement of the adaptive capacity of both natural and planted forests may help to decrease the vulnerability of those whose livelihood depend on forest goods and services, especially the poorest (Innes and Hickey, 2006). Also, without management for adaptation, the current potential of tropical forests to both remove and store atmospheric carbon may diminish thus feeding a positive feedback of carbon emissions (e.g. Gitz and Ciais, 2004). In cases where forests and forestry make, or are perceived to make, minor contributions to national economies (e.g. Keller *et al.,* 2007), governments may be more concerned with ensuring adaptation in other productive sectors such as agriculture or water supply (Guariguata *et al.,* 2007). In line with the importance of forests and forestry in CC mitigation/adaptation and its role in socio-economics particularly forest exploitation for timber and non-timber forest products, there is necessity for adapting tropical forest management practices to CC.

This is an aspect of sustainable forest management which provides a method of balancing diverging priorities of sustainable economic and social development on the one hand, and ecological sustainability on the other owing to the fact that forestry is still expected to play its traditional roles of ecological stabilization and at the same time, engender economic development (Popoola and Akande, 2001). **Table 32.4** gives a broad classification of approaches and actions that may be needed in this regard, using forests managed for timber production, as an example.

Table 32.4: A broad classifications of approaches and actions that may be needed for adapting tropical forest management for timber production to climate change

Approach	Actions by forest management type	
	Natural forest management based on selective logging	Tree plantations
Facilitating adaptive capacity of timber Species	Maximize juvenile population sizes Maximize reproductive population sizes Maintain inter-population movement of pollen and/or seeds by minimizing harvesting impacts on forest structure through reduced impact logging and by maximizing landscape connectivity Maximize genetic variation of planted seedlings when enriching logging gaps Use of Tran located material in enrichment planting	Plant a range of genotypes and "let nature take its course" Implement appropriate species selection (particularly in transitional zones) Use seed sources adapted to expected future conditions Use "stable" genotypes that tend to perform acceptably in a range of environments
Other silvicultural and management approaches	Intensify liana removal Minimize levels of slash through reduced impact logging Widen buffer strips/fire breaks	Plant mixtures of species and implement appropriate species selection Widen buffer strips/fire breaks
Institutional/policy	Increase awareness about enhancing the adaptive capacity of forests to climate change and define practical approaches and policies to this end Promote good practices for fire management within, and adjacent to, production forests Promote seed exchange and participatory genetic improvement programs for smallholders Mainstream adaptation into national development in the context of the forestry sector Evaluate costs and benefits of forestry activities aimed at enhancing the adaptive capacity of forests and establish appropriate financial mechanisms for implementation	

Necessity for incorporating climate change related research outputs into agricultural and renewable natural resources education in Africa

Africa is described as very vulnerable to CC because of a high dependence on agricultural/RNRs and because large poor populations live in marginal (drought or flood-prone) climates. In addition, many African countries' capacity to adapt to CC is said to be limited by a lack of resources, poor institutions and inadequate infrastructure (Ulsrud and Eriksen, 2007). There is no doubt that many people in Africa are vulnerable to CC, although it is important to focus on which specific populations are vulnerable and why they are vulnerable. In specific, many poor people are vulnerable to CC, and droughts or floods can indeed force individuals and families into destitution (Lind and Eriksen, 2006).

It is important as this juncture to be aware of the distinction between poverty and vulnerability since development measures commonly used in order to reduce poverty do not necessarily reduce vulnerability to CC. There are even well documented cases of projects aimed at reducing poverty that have increased vulnerability to difficult climate conditions. Economic growth and technological change does not necessarily reduce vulnerability to climate variability and change, and can increase it (Ulsrud and Eriksen, 2007). For example, the conversion of mangroves into shrimp farms may generate economic gains but leave coastal communities more vulnerable to coastal hazards such as storm surges (Adger *et al.,* 2003).

Agricultural and RNR sector and other income generating activities for rural populations has been seen as areas that will be worst hit by this phenomenon particularly as a result of increased variability, heat stress, flooding and drought caused by CC (McCarthy *et al.,* 2001). The changes will reduce yields in many locations while improving them in others. Even if the net effects are still uncertain, there is little doubt that many areas will be adversely affected (McCarthy *et al.,* 2001).

Agriculture is an important source of income for many poor people. It is thus predicted that CC and climate variability can increase poverty levels particularly in tropical regions. In Africa, estimates indicate that nearly 60-70% of the population is dependent on the agriculture sector for employment (Ulsrud and Eriksen, 2007) a region where farming mainly depend on rain-fed agriculture. Research outcomes have predicted that increased droughts can seriously impact the availability of food. Nevertheless, agricultural and RNR production has the potential to contribute to CC mitigation on two fronts; through the amendment of everyday operations to reduce emissions and utilising some crops as sustainable energy sources to reduce CO_2 emission. In line with the above, there is necessity for incorporation of up-to-date information regarding CC in agricultural and RNR education to increase capacity and forestall the problems earlier identified as a result of global CC.

Conclusion

The fact that most of the inhabitants of SSA, particularly those in the rural areas are dependent on agricultural and other RNR cannot be overemphasised. This has necessitated suggestions/recommendations targeted at sustainable means of generating these resources in such a way as to sustain livelihood and/or alleviate poverty in this part of the world, particularly as it concerns the Millennium Development Goals. Recent observation among many others has shown that climate variability is already and/or will have influences (negative and positive) on sustainable production and use of these resources. Thus, the various interrelationships existing between CC and agricultural/RNR production and use need to be studied and/or researched into and documented as being done in many of the developed countries.

Presently, capacity for research in terms of human, facilities, and financial resources are still comparably lower in Africa, most especially in SSA. This particular growth/developmental challenge still have impacts on R and E concerning CC in this region. It is noteworthy that challenges still exist in this area even in the developed countries. Therefore, needless to say that sustained more R and E is necessary in this area, particularly CC mitigation and adaptation strategies most especially for SSA and its inhabitants. In line with this, it will be beneficial for outcomes of contemporary studies/researches in CC to be incorporated into agricultural and RNR education in this part of the world where there is still the aspiration to catch up with the developed countries, in terms of growth and development in every sphere of human endeavour, even with the current level of environmental degradation caused by pollution from the developed countries.

In order to avoid future worsening scenario of CC, it will be important that developing countries make use of the available technologies and information on CC, as they are expected to grow and develop. This will assist in avoiding the past mistakes made by the developed countries concerning the production of substances that has contributed to global CC. It is also imperative to improve the present out-dated research, teaching and learning curricula and facilities in research and academic institutions in many parts of this region. This is expected to contribute to the efforts at increasing/updating information and knowledge base in R and E in general and CC in particular in order to increase the capacity for sustainable production and use of agricultural and RNR in SSA.

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33. Triple Mission of the Faculty of Agriculture and Forestry, University of Ibadan, Nigeria: A Lens on a Decade of Staff Capacity Building and Production of Graduates

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Abstract

Teaching, research and community engagement constitute the triple mission of a University. This paper interrogates academic units in the Faculty of Agriculture and Forestry, University of Ibadan, Nigeria from 1998 to 2007 with a view to stimulating a national dialogue on achieving the goal of the University towards the production of graduates whose training in a liberal educational tradition will enable them to deal with the increasingly specialised problems of Agricultural production and Natural Resources. The study was conducted to review and examine the status of academic staff and graduates from 1998 to 2007; investigate capacity building and determine activity level of academic staff on board against optimum staff; examine interpersonal relation skills and mentoring; and identify challenges facing the Faculty of Agriculture and Forestry. The results showed that academic staff disposition is grossly inadequate. There was an upward and downward trend in graduates' production with a corresponding decline in the number of academic staff. Capacity building for human resources was inadequate. The activity level of academic staff showed that the Department of Agricultural Extension and Rural Development was academically efficient with activity level of 1.0 followed by Departments of Agronomy; Wildlife and Fisheries; Animal Science and Crop Protection and Environmental Biology with 0.76, 0.71, 0.65 and 0.63 activity levels respectively while the least activity level of 0.48 was obtained in the Departments of Forest Resources Management and Agricultural Economics. It was affirmed that interpersonal relation skills was fair while mentoring among lecturers and students was very high. Funding, logistics, infrastructural facilities, laboratories, advancement in Information and Communication Technology (ICT) and power supply, were identified as challenges facing the Faculty. It is recommended that a holistic response should be charted for Triple Mission of a University so that we do not simply end up creating new problems.

Key words: Optimum staff, activity level, interpersonal relation skills, mentoring, infrastructure

Introduction

University education in Nigeria ante-dated the gaining of political independence from Britain in October 1960. The premier and the only university institution then, the university college, Ibadan (now University of Ibadan), was established in 1948. The socio-economic growth and political modernisation of the decade of the 1950s intensified the demands for high level manpower in both the public and private sectors. During these twilight years of the colonial era, the burden and challenge of internal self-government began to devolve on the educated elites in the Northern, Eastern and Western Regions—the three regions making up the Federation. The nation witnessed tremendous upsurge in education at the primary and secondary school levels during the decade, and it soon dawned on the Nigerian nationalists and the policy-makers that one University institution had become grossly inadequate to cope with the imperatives of an expanding economy. Over the years, a number of Universities have sprung up at federal and state levels complemented even by private universities for the teeming population in Nigeria.

University is an institution of learning with its body of teachers, students, graduates, its colleges and faculties and is empowered to grant degrees. University is designed to stimulate enquiry and produce knowledge through the organised collection, collation, analysis and interpretation of facts about the world.

The basic goal of the University is to produce graduates whose training in a liberal educational tradition will enable them to deal with the increasingly specialised problems of our society and whose intellectual accomplishments and mental perspective will prepare them to operate on a more encompassing level outside their areas of specialisation (Olaniyan and Elufowoju, 1983). However, the vision of a University is to expand the frontiers of knowledge and transform the society through innovation. The mission of the University is to be a world-class institution where conditions for learning are excellent, research and services are outstanding, and where staff and students are worthy in character and sound judgement. In other words, the mission of the University is to provide a conducive environment, the facilities and the competent personnel dedicated to the advancement of knowledge and its practical application to the needs of a modern society (Olaniyan and Elufowoju, 1983).

The United Nations Educational, Scientific and Cultural Organisation (UNESCO) in its Education for Sustainable Development Information Brief indicates that ‘‘*Higher Education…occupies an important position in shaping the way future generations learn to cope with the complexities of sustainable development*’’. UNESCO (2005) notes further that universities form a link between knowledge generation and transfer to society in the work they do to prepare future decision-makers. They also play an important role in generating new knowledge that shapes and influences the decisions made by governments, industry and other stakeholders. University contributes to societal development through providing a service to society (knowledge generation and access to knowledge is a ‘public good’) and through more direct community engagement work.

History of Faculty of Agriculture and Forestry

The Faculty of Agriculture, University of Ibadan, Nigeria was established in 1949 as a one department faculty for the advancement of agriculture by the application of science through teaching and research (Faculty of Agriculture and Forestry Undergraduate Prospectus, 2004). In 1962, the activities of this comprehensive department were split into four Departments of Agriculture; Agricultural Biology; Agricultural Chemistry and Soils; and Agricultural Economics. In 1963, three new Departments were created, namely the Departments of Forestry; Veterinary Medicine; and Veterinary Anatomy and Physiology. Consequently at the same time, the name of the faculty was metamorphosed to the Faculty of Agriculture, Forestry and Veterinary Science.

In 1966/67, a further reorganisation of the faculty was carried out. The Departments of Agriculture and Agricultural Chemistry and Soils were re-named as Agronomy and Animal Science. In 1975, the Departments of Veterinary Anatomy and Physiology, Veterinary Medicine and Surgery became a Faculty of Veterinary Medicine. The Departments of Agricultural Extension Services came into being during 1975/76 session while the Department of Wildlife and Fisheries Management was created in 1981/82 session to make a total of seven departments in the Faculty. In 1995/96 session, the Department of Agricultural Biology became the Department of Crop Protection and Environmental Biology, while the Department of Agricultural Extension Services became the Department of Agricultural Extension and Rural Development in the 1998/99 session. The academic departments constituting the Faculty of Agriculture and Forestry nowadays are as follows:

1. Department of Agricultural Economics
2. Department of Agricultural Extension and Rural Development
3. Department of Agronomy
4. Department of Animal Science
5. Department of Crop Protection and Environmental Biology
6. Department of Forest Resources Management

Triple Mission of University

Teaching, Research and Community Engagement (TRCE) constitute the 'Triple Mission' of a University (United Nations Environment Programme, 2006). Most University teaching academic members of staff have some responsibilities for teaching, research and community engagement. However, the balance of 'workload' across these three focus areas differ depending on: (i) the position of the staff member concerned; (ii) the priorities of the University, faculty, department, programme or unit; and (iii) the conditions of service that exist within the University. Teaching, research and community engagement roles are often linked to the academic interests of particular University teachers/researchers.

Given the triple mission of a university, the following are required in considering the roles and functions of a University in promoting sustainable development: (a) increasing the relevance of teaching and research for societal problems leading to more sustainable livelihoods; (b) improving the quality and efficiency of teaching and research; and (c) bridging the gap between science and education, traditional knowledge and education.

This paper interrogates the academic units in the Faculty of Agriculture and Forestry, University of Ibadan, Nigeria from 1998 to 2007 with a view to stimulating a national dialogue on achieving the goal of education for sustainable development innovations in the University towards the production of graduates

Capacity Building

The development of knowledge, skills and attitudes in individuals and groups of people relevant in design, development management and maintenance of institutional and operational infrastructure and processes that are locally meaningful. The ability of individuals and organisations or organisational units to perform functions effectively, efficiently and sustainably reflects on their capacity (UNDP, 1998). This is a broader approach while still focusing mainly on staff development. Capacity Building is viewed in a wider context to include the ways and means by which the overall goals are achieved.

Review and status of academic staff in the Faculty of Agriculture and Forestry

The Faculty came to existence 59 years ago and both expatriates and indigenous academic staff were employed with limited number of students. The academic staff then could cater for limited number of academic teaching courses, research and community engagement. About 48 years ago, a few universities were established to complement University of Ibadan. However, virtually all the 36 states in the Federation of Nigeria have Universities to cater for the increasing population in Nigeria.

The Faculty of Agriculture and Forestry, University of Ibadan, Nigeria has 26 Professors; 10 Readers (Associate Professors); 21 Senior Lecturers; 37 Lecturer I; and 15 Lecturer II grades. The total number of academic staff on board in the seven departments making up the Faculty of Agriculture and Forestry is 109. However, a total number of 169 academic staff is required for optimum academic staff performance. This shows that the Faculty is deficient by a total of 60 academic staff (Figure 33.1). Despite this, a number of professors in the next 5 years will retire. Nevertheless, the University Council in the last two years has been recruiting new staff for replacement, but the replacement strategy is not commensurate with quick succession that ought to bring equilibrium in terms of experience in teaching, research and community engagement.

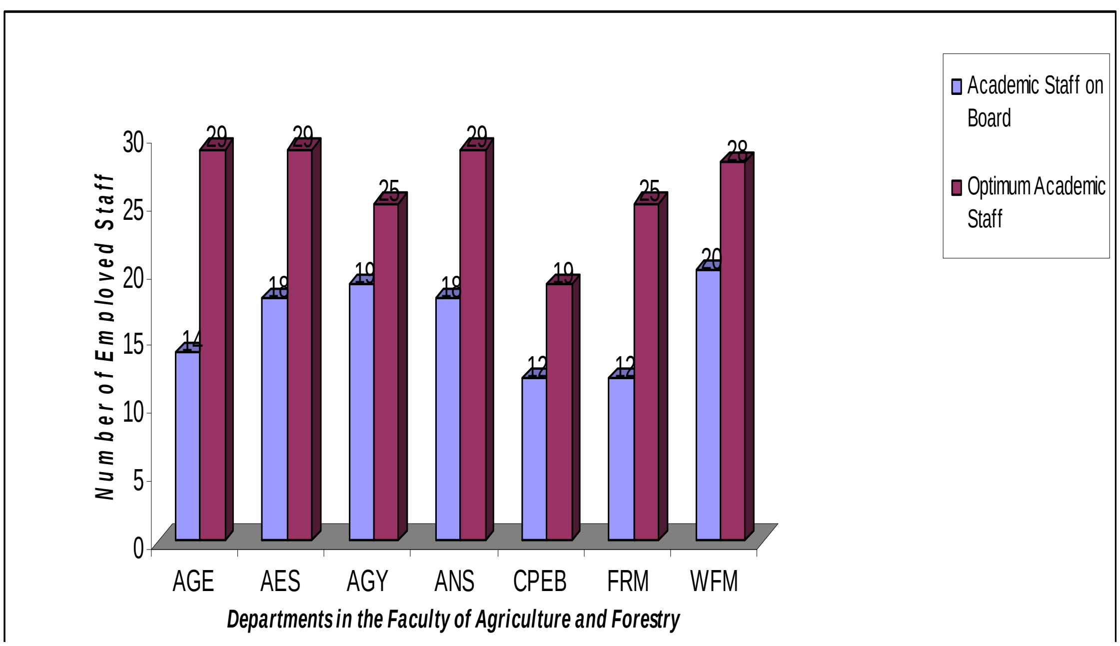

Figure 33.1. Academic staff on board versus required optimum staff

Graduates produced in the faculty of agriculture and forestry for a decade (1998 to 2007)

The Faculty of Agriculture and Forestry recorded upward and downward trends in the number of undergraduates and postgraduates produced from 1998 to 2007 (Tables 33.1-33.3). The reasons for these upward and downward trends were instability in the economy of Nigeria, increases in tuition fees and creation of more universities that run parallel courses with University of Ibadan. The Faculty produced from 1998 to 2007 a total of 1,913 Bachelor of Science Degrees (B.Sc.); 1,826 Master of Science Degrees (M.Sc.); 21 Master of Philosophy (M.Phil.); and 362 Doctor of Philosophy Degrees (PhD). However in 2002, no graduates were produced because the academic session was cancelled in the calendar of the University.

From 1998 to 2007, classification of grades showed that at undergraduate level, the Faculty had 34 First Class; 430 Second Class Upper Division; 1210 Second Class Lower Division; 224 Third Class Division; and 66 with Pass. The Faculty also recorded a total of 51 graduates as mainstream.

Capacity Building

Is capacity building given a prominence in the Faculty of Agriculture and Forestry, University of Ibadan, Nigeria?

A lens on optimum staff recruitment; staff on board; and activity level in the academic units of the seven departments in the Faculty of Agriculture and Forestry, University of Ibadan, Nigeria were used to answer this question.

Table 33.1. Graduates in the Department of Agricultural Economics and Rural Development from 1998 to 2007

Year	No. of B.Sc.	No. of M.Sc.	No. of M.Phil.	No. of Ph.D.		No. of B.Sc.	No. of M.Sc.	No. of M.Phil.	No. of Ph.D.
Department of Agronomy (AGY)						Department of Agricultural Extension and Rural Development (AES)			
1998	81	133	-	1		34	35	-	1
1999	42	-	-	1		18	7	-	1
2000	86	90	1	13		21	19	-	14
2001	66	55	-	5		19	22	-	5
2002	-	-	-	-		-	-	-	-
2003	86	137	-	6		25	45	2	5
2004	42	86	-	3		39	-	-	5
2005	99	82	-	5		46	28	-	4
2006	64	16	-	11		41	32	2	2
2007	16	7	-	5		11	31	-	2
Total	582	606	1	50		254	219	4	39

Source: University of Ibadan Order of Proceedings for Graduation from 1998 to 2007

Table 33.2. Graduates in the Department of Agronomy and Animal Science from 1998 to 2007

Year	No. of B.Sc.	No. of M.Sc.	No. of M.Phil.	No. of Ph.D.		No. of B.Sc.	No. of M.Sc.	No. of M.Phil.	No. of Ph.D.
Department of Agronomy (AGY)						Department of Animal Science (ANS)			
1998	29	41	-	9		30	53	-	6
1999	18	1	-	7		18	8	-	5
2000	24	47	-	11		28	41	1	5
2001	28	18	-	9		36	25	-	1
2002	-	-	-	-		-	-	-	-
2003	31	40	-	7		32	51	-	11
2004	54	32	-	13		67	31	-	13
2005	55	26	-	3		60	17	-	3
2006	38	18	2	6		38	43	-	5
2007	20	21	-	10		20	37	-	11
Total	297	244	2	75		329	306	1	60

Table 33.3. Graduates in the Department of Crop Protection and Forest resources and Environmental Biology from 1998 to 2007

Year	No. of B.Sc.	No. of M.Sc.	No. of M.Phil.	No. of Ph.D.		No. of B.Sc.	No. of M.Sc.	No. of M.Phil.	No. of Ph.D.
Department of Crop Protection and Environmental Biology (CPEB)						Department of Forest Resources (FRM)			
1998	30	20	-	9		14	26	-	1
1999	1	20	2	3		2	-	-	1
2000	23	21	1	5		8	11	1	4
2001	16	16	-	6		6	18	-	2
2002	-	-	-	-		-	-	-	-
2003	25	26	2	-		14	31	-	12
2004	22	28	1	8		19	14	-	-
2005	27	-	1	7		24	-	-	4
2006	25	19	1	2		21	9	-	4
2007	17	12	1	3		3	8	-	3
Total	186	162	9	43		111	117	1	31

Optimum Staff Demand

This refers to the total number of academic members of staff at any time that is most favourable for the achievement of an aim or result of teaching, research and community service (Popoola and Agbeja, 2007). Therefore, the categories of members of academic staff at any given time for smooth succession and replacement of retired academics should include Professors; Readers; Senior Lecturers; Lecturers I; Lecturers II; Assistant Lecturers; Graduate Assistants; and

Technicians. The seven departments in the Faculty of Agriculture and Forestry have 38 Academic units. A total of 109 academic staff is currently employed whereas the optimum academic staff for various courses taught in the seven departments should be 169 (Tables 33.4-33.11). Presently, there is gross inadequate staff disposition. In considering the triple mission of the Faculty of Agriculture and Forestry (i.e. Teaching, research and community engagement) for societal processes leading to more sustainable patterns of life, the optimum staff demand in the Faculty of Agriculture and Forestry (OSD) is a function of Structure of Employment; Category of Full Staff Strength; and Activity Level of Staff (Agbeja, 2007).

Where,
OSD = Optimum Staff Demand

$$= \frac{\text{Number of Each Category of Staff}}{\text{Total Number of Staff on Board}}$$

= Ranges from Graduate Assistant, Assistant Lecturer, Lecturer II, Lecturer I, Senior Lecturer, Reader (Associate Professor) and Professor

$$= \frac{\text{Actual Number of staff on Board}}{\text{Optimum Staff based on Empirical Norm}}$$

AGE = 14/29 = 0.48; AES = 14/14 = 1; AGY = 19/25 = 0.76;
ANS = 18/29 = 0.62; CPEB= 12/19 = 0.63; FRM = 12/25 = 0.48; and
WFM =20/28 = 0.71

Table 33.4. Academic Staff on Board versus Optimum Academic Staff in the Department of Agricultural Economics

Academic Units	**Staff on Board**	**Status of Staff on Board**	**Optimum Staff**
Production Economics and Farm Management	2	Senior Lecturer (1) Lecturer 1 (1)	4
Resource and Environmental Economics	3	Reader (1) Lecturer 1 (2)	6
Agricultural Business, Financial Management and Marketing	4	Professor (2) Lecturer (1) Lecturer II (1)	7
Agricultural Planning and Policy	3	Professor (1) Reader (1) Senior Lecturer (1)	6
Welfare Issues	2	Lecturer II (2)	6
Total	14		29

Number in parenthesis ( ) represents the number of category of staff in each academic Unit

Table 33.5. Academic Staff on Board versus Optimum Academic Staff in the Department of Agricultural Extension and Rural Development

Academic Units	**Staff on Board**	**Status of Staff on Board**	**Optimum Staff**
Agricultural Extension	6	Reader (1) Senior Lecturer (3) Lecturer 1 (2)	6
Home Economics	2	Lecturer 1(2)	2
Communication	4	Lecturer 1 (4)	4
Rural Sociology	2	Professor (2)	2
Total	**14**		**14**

Number in parenthesis ( ) represents the number of category of staff in each academic Unit

Table 33.6. Academic Staff on Board versus Optimum Academic Staff in the Department of Agronomy

Academic Units	**Staff on Board**	**Status of Staff on Board**	**Optimum Staff**
Crop Production	6	Professor (3) Reader (1) Senior Lecturer (1) Lecturer 1 (1)	7
Soil Science	8	Professor (3) Senior Lecturer 3 Lecturer II (2)	13
Horticulture	3	Senior Lecturer (2 Lecturer 1(1)	3
Agricultural Mechanization	2	Reader (1) Lecturer II (1)	2
Total	19		25

Number in parenthesis ( ) represents the number of category of staff in each academic Unit

Table 33.7. Academic Staff on Board versus Optimum Academic Staff in the Department of Animal Science

Academic Units	Staff on Board	Status of Staff on Board	Optimum Staff
Agricultural Biochemistry	5	Professor (3) Lecturer 1 (1) Lecturer II (1)	4
Animal Nutrition	4	Professor (1) Senior Lecturer (2) Lecturer 1 (1)	3
Animal Production and Management	4	Lecturer 1(1) Lecturer II (3)	6
Animal Breeding and Genetics	2	Reader 1 (1) Lecturer 1 (1)	3
Animal Physiology and Bioclimatology	1	Reader 1 (1)	5
Animal Products and Meat Science	1	Lecturer 1 (1)	4
Forage Production and Management	1	Lecturer II (1)	4
Total	18		29

Number in parenthesis ( ) represents the number of category of staff in each academic Unit

Table 33.8. Academic Staff on Board versus Optimum Academic Staff in the Department of Crop Protection and Environmental Biology

Academic Units	Staff on Board	Status of Staff on Board	Optimum Staff
Environmental Biology	6	Professor (1) Reader (2) Senior Lecturer (1) Lecturer 1(1) Lecturer 11 (1)	9
Entomology	2	Professor (1) Senior Lecturer (1)	5
Phytopathology	4	Professor (2) Senior Lecturer (1) Lecturer II (1)	5
Total	12		19

Number in parenthesis ( ) represents the number of category of staff in each academic Unit

Table 33.9. Academic Staff on Board versus Optimum Academic Staff in the Department of Forest Resources Management

Academic Units	**Staff on Board**	**Status of Staff on Board**	**Optimum Staff based on Empirical Norm**
Silviculture and Biology	2	Professor (1) Reader (1)	5
Forest Economics and Management	4	Professor (1) Lecturer 1 (3)	5
Wood Science	3	Senior Lecturer (1) Lecturer 1 (2)	5
Forest Biometrics	3	Professor (1) Senior Lecturer (1) Lecturer 1 (1)	5
Agroforestry	-	None	5
Total	12		25

Number in parenthesis ( ) represents the number of category of staff in each academic Unit

Table 33.10. Academic Staff on Board versus Optimum Academic Staff in the Department of Wildlife and Fisheries Management

Academic Units	**Staff on Board**	**Status of Staff on Board**	**Optimum Staff based on Empirical Norm**
Aquaculture and Fish Nutrition	4	Professor (2) Lecturer 1 (1) Lecturer II (1)	4
Fish Processing, Utilization and Gear Technology	1	Senior Lecturer (1)	2
Fishery Policy, Economics and Marketing	3	Senior Lecturer (1) Lecturer 1 (1) Lecturer II (1)	4
Oceanography and Seamanship	1	Lecturer 1(1)	2
Fisheries Ecology, and Management	4	Senior Lecturer (1) Lecturer 1 (3)	4
Wildlife Domestication, Nutrition and Utilization	1	Professor (1)	2
Wildlife Economics and Management	1	Lecturer 1 (1)	2
Wildlife Ecology and Protected Area Management	3	Professor (1) Lecturer 1 (2) Lecturer 1 (1)	4
Environmental Sensitivity and Impact Assessment	1	Lecturer 1 (1)	2
Ecological Recreation	1	Lecturer 1 (1)	2
Total	**20**		**28**

Number in parenthesis ( ) represents the number of category of staff in each academic Unit

Table 33.11. Interpersonal Relation Skills between Lecturers and Students

Respondents	Distribution of Responses on Interpersonal Relation Skills			
Military Era		Civilian Era		
	Cordial Relationship	Not Cordial Relationship	Cordial Relationship	Not Cordial Relationship
Lecturers	4	31	20	15
Students	10	60	39	31
Total	14(13.3%)	91(86.67%)	59(56.19%)	46(43.81%)

Each academic unit should be endowed with optimum number of staff in accordance with empirical norm as follows: Professor, Reader, Senior Lecturer, Lecturer 1, Lecturer II, and Assistant Lecturer/Graduate Assistant. The arrangement is such that it is flexible according to succession in hierarchy and also in line with promotion exercise. Considering the 38 academic units (Tables 33.1-33.3) subsisting in the seven departments making up the Faculty of Agriculture and Forestry, the activity level of academic staff showed that AES was academically efficient with activity level of 1.0 followed by Departments of AGY; WFM; ANS and CPEB with 0.76, 0.71, 0.65 and 0.63 activity levels, respectively while the least activity level of 0.48 was obtained in the Departments of Forest Resources Management and Agricultural Economics. Apart from the Department of Agricultural Extension and Rural Development that had activity level equals 1, all other six departments are deficient in staff complement. It was a serious phenomenon in the Departments of FRM and AGE. The implication is that from 1998 to 2007, the academic staff in the other six departments have been overloaded with responsibilities in teaching, research and community development. Therefore, the Faculty of Agriculture and Forestry is grossly inadequate of staff disposition to a total number of 60 academic staff. These findings negate capacity of academic staff as the ability of individuals and organisations or organisational units to perform functions effectively, efficiently and sustainably. The implication is that the workload on each lecturer is more than his/her normal delegation of authority. Therefore, the academic staff were overstretched.

Interpersonal relation skills and mentoring

University Re-orientation (Interpersonal Relation Skills)

Lecturer-lecturer, student-student and lecturer-student relationships are of cardinal importance in teaching and innovative research. Both lecturers and students affirmed that there the prolonged military era in Nigeria exacerbated the relationship among government, lecturers and students. The relationship among government National Universities Commission, academic staff and students were very poor to the extent that industrial actions were the order of the day between Nigerian Government and Academic Staff Unions; students were not free with lecturers, while the top-bottom relationship among academics was neither cordial nor result-oriented. A case worthy of note then was when individuals withheld useful information that could trigger innovative research or benefit other colleagues, students, Departments and the entire Faculty at large. Table 33.11 shows that the responses from both lecturers and students however, affirmed that the relationship among Government, lecturers and students had been fair from 1999 to date.

They however, complained that issues on educational standard that could stimulate national dialogue were jettisoned by the government, hence, the carry-over of military dictators' still prevail in the educational sector in Nigeria.

Mentoring

A sense of purpose and the ability to be purposeful is a key to lecturers and students successes. Mentoring has been identified as a powerful personal development and empowerment tool for innovative teaching and research in the seven Departments of the Faculty of Agriculture and Forestry, University of Ibadan, Nigeria. This is an effective way the Faculty has been helping lecturers and students to progress in their careers and is becoming increasingly popular as its potential is realized. The Faculty over the years has been able to help each lecturer to build a solid personal foundation and demonstrate strong confidence in self and others; develop personal vision and uncover value priorities; think strategically and inspire shared vision, mission and values; determine appropriate goals, strategies, tactics and action plans; and elicit high commitment to personal change and development.

The most important fact about the seven departments in the Faculty of Agriculture and Forestry is that they are a flagship in high-level manpower training in education in more than 89 Nigerian Universities and some African countries. The implication of mentoring in the Faculty of Agriculture and Forestry, University of Ibadan, Nigeria is that effective means of evoking purposefulness, and so generate high levels of motivation and corporate intent is very high.

Challenges

Funding, logistics (e.g. tractors and vehicles), infrastructural facilities, laboratories, ICT and power supply were seen as the challenges facing the Faculty of Agriculture and Forestry, University of Ibadan, Nigeria.

Funding

Funding has been a serious problem because the budgetary allocation to all Federal Universities has increased over the last ten years as a result of more universities being created in the country. However, the University of Ibadan is now surmounting the problem via direct allocation of funds to each department in various faculties in the University.

Logistics

Logistics such as buses, cars and tractors to run the daily activities in Faculty have been problematic since the introduction monetization during Chief Olusegun Obasanjo's tenure as the president of Nigeria from 1999 to 2007. A lot of vehicles were boarded without replacement. Even those vehicles that were grounded could not be repaired. The University has started purchasing vehicles for principal officers and there is a belief, the faculties will benefit in the area of logistics in the immediate term.

Infrastructure

Infrastructural facilities such as buildings, roads, water, laboratories and electricity also have impacted on teaching and research in the Faculty of Agriculture and Forestry. Six out of seven Departments in the Faculty of Agriculture and Forestry have conducive buildings for teaching and research. The only department that is deficient of its own building is the Department of Wildlife and Fisheries Management. The coping strategy, however, developed as far back as 1981 was that the Department was and is still being accommodated in the building belonging to the Department of Forest Resources Management. The capacity of the building is nowadays overstressed. The University Authority is now planning to construct a separate building for the Department of Wildlife and Fisheries Management in order to accommodate both lecturers and students for smooth and effective teaching and research.

Roads and Water

Maintenance of roads on campus nowadays is good to facilitate movement of people and even for people. In the last two years, the University Authority embarked on maintenance of roads to Faculties and residential avenues.

Apart from erratic power supply to pump water from the reservoir to various academic departments and residential buildings on-campus, potable water supply on campus has been fair.

Laboratories

Laboratories used to be run down. Five years ago, through direct teaching, research and laboratory (DTRL) fund allocation to each department in the Faculty of Agriculture and Forestry, significant changes have been recorded in terms of new equipment and tools. All field stations have been improved for conducive research. The lecturers and students can now be proud of the outcomes of their research findings.

Electricity

This is affecting all economic sectors in Nigeria including the Educational sector. Supply of electricity from 1999 to date has been a bottleneck for every sector in Nigeria. This has since been retarding the progress of teaching and research. However, the coping strategy being adopted in the seven Departments is installation of generating power plants. Changes are needed in improving power generation.

Conclusion and Recommendations

Conclusion

Capacity building in the Faculty of Agriculture and Forestry, University of Ibadan has impacted the production of graduates from 1998 to 2007. The intellectual accomplishments and mental perspective from both lecturers and graduates could be significantly achieved if the Government is ready to see Universities as a harbinger to development of a Nation. A holistic response to innovative teaching and research is needed from academic departments in the Faculty of Agriculture and Forestry. All over the world, Universities are operating in a new and rapidly changing environment.

Recommendations

The following are recommended for effective teaching and innovative research in order to stimulate a national dialogue on achieving the goal of the University towards the production of graduates:

- Policy towards holistic response be charted for Triple Mission of a University
- Policy drive towards enabling environment for staff interaction.
- Policy towards creating interactive session between 'staff and student' and 'staff and staff' and evaluation of lecturers by students
- Policy on the use of student evaluation and teaching regimes as part of staff promotion exercise
- Policy drive towards adequate funding

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34. Shaping African Tertiary Agricultural Education Towards Responsiveness to Emerging Global Challenges

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Abstract

Africa's economic growth is closely linked to the performance of smallholder agricultural sector. This sector increasingly faces new global challenges including food crises, rising fuel prices, climate change, loss of biodiversity and degradation of natural resources. Much of these are probably linked to climate change. These conditions in southern Africa particularly, will lead to decreased maize production, the staple crop in the region, leading to widespread famine. For the smallholder sector in southern Africa to be able to absorb the shock posed by climate change, market risks and other threats, it is important that key drivers for sustainable agricultural production are in place. Central to making the drivers operational is the production of a large pool of suitable graduates who are well trained and equipped to work with and help rural communities to meet these emerging challenges. Recent symposia of the African Network for Agriculture, Agroforestry and Natural Resources Education (ANAFE), Sustainability, Education and Management of Change in the Tropics (SEMCIT) and Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) concluded that the agricultural graduates currently being produced in tertiary agricultural institutions in Sub-Saharan Africa (SSA) are deficient in certain critical areas that may compromise their ability to respond to the challenges enumerated above. The curricula need to be more responsive to the real life situation of the new crop of graduates. Key courses which need to be included in the curricula include climate change, biotechnology, information and communication technologies, agroforestry, post-harvest technology and irrigation and water management. Coupled with equipping the students with the necessary soft-skills, basic understanding of these emerging challenges and how to deal with them will strengthen their capacity in the world of work in contributing to farmers' circumstances. There is need for hybrid programmes that provide rounded skills in these challenging areas.

Key words: Climate change, smallholder sector, tertiary agriculture institutions, curricula, graduating students

Introduction

The economic conditions in Africa have been described to be dire and deteriorating. Africa is the only continent where hunger and poverty are projected to get worse in the future (Rosegrant *et al.,* 2005). Statistics show that 80 % of all Africans live on a daily income of less than US$2 while nearly half struggle to survive on US$1 a day or less (Johnson and Hazell, 2002). If change is going to be achieved, then agriculture, particularly smallholder agriculture has to be made to work in the continent. According Hazell and Johnson (2002), agriculture accounts for 70 % of fulltime employment in Africa, 33 % of total GDP and 40 % of total export earnings.

In 2000, the world community adopted eight millennium development goals (MDGs) that aimed to promote human development and reduce poverty, hunger and disease. Some developing regions and countries are making progress toward these goals but in many categories measured, including food security, the situation in Africa is stagnant or worsening. More than 200 million Africans now suffer from malnutrition (Rosegrant *et al.,* 2005) and the situation is projected to worsen in the future. What contribution can capacity building at agricultural tertiary institutions in SSA make in order to contribute to the targets set by the MDGs?

This paper reviews how curricula at most tertiary agricultural institutions in SSA have failed to deliver to meet challenges consistent with sustainable production. It argues that the focus in the teaching has been on the traditional methods and most of the graduates produced were meant to serve the public sector research and extension systems. The paper goes further to suggest what needs to be done to produce graduates from these tertiary institutions who will be able to champion the process for tackling current challenges being faced in agricultural production in sub-Saharan Africa.

African growth prospects

Agriculture remains the foundation of SSA's dominant economic activity accounting for 40 % of GDP, 15 % of export earnings and 60 to 80 % of employment (Diao *et al.,* 2006). Productivity of African agriculture over the last two decades has generally stalled. Per capita output of staple foods continues to fall and the continent is steadily losing its world market share for major export crops like coffee, tea and cocoa. Improving performance of Africa's stagnating agricultural sector is a key to solving the problems of hunger and poverty. The only way of ensuring improved African agriculture is ensuring that the prime movers for its development are in place.

Key drivers for sustainable agricultural production

Rukuni (2002) lists five basic prime movers which should work in a concerted manner to achieve sustainable agricultural development. These include:

- New technology produced by public and private investments in agricultural research or imported from the global research system and adapted to local conditions
- Human capital in the form of professional, managerial and technical skills produced by investments in schools, agricultural colleges, faculties of agriculture and on the job training and experience,
- Sustained growth of biological capital (genetic and husbandry improvements of livestock herds, crops, forests, plantations and so on) and physical capital investments (large and small dams, irrigation, grain stores and roads),
- Improvements in the performance of institutions such as marketing, credit, research, extension and land reform, and
- Favourable economic policy environment.

No single prime mover can increase agricultural production and sustain it for any period of time. However, central to making the prime movers operational is the production of necessary human resources to man the different institutions which will "get agriculture moving".

Current tertiary agricultural graduates

The major shortcomings in tertiary agricultural education have been associated with 1. Student selection process, 2 Institutional management, 3. Curricula design and 4. Curricula delivery (Table 34.1). A number of symposia including the Sustainability, Education and Management of Change (SEMCIT) series which ran from 1999 to 2003; the African Network for Agriculture, Agroforestry and Natural Resources Education (ANAFE) of 2003 and the Regional Universities Forum for Capacity Building in Agriculture) RUFORUM of 2007 have analysed the current shortcomings of current tertiary agricultural education. A summary of the findings in these symposia is given in Table 34.1.

The SEMCIT, ANAFE and RUFORUM symposia all have come to the conclusion that the agricultural graduate currently being produced in SSA is not suitable for the task at hand. They propose that there is a need to change the student selection process, lobby for more support to the tertiary agricultural institutions and redesign the curricula to bring out a product demanded by the stakeholders. They propose that the current graduate who will be the agricultural leader must:

- Have positive values and high ethical standards
- Committed to rural communities
- Possess entrepreneurial skills
- Have social consciousness
- Committed to the environment and conservation of biodiversity
- Solid grounding in scientific and technical principles
- Have practical experience
- Have generalist preparation
- Be a life-long learner
- Be a strong leader and team builder and
- Excellent interpersonal and communication skills

Taking that this is the way to go, curricula content and delivery will play a central role in ensuring that the goals associated with the needed change are achieved.

Towards building a responsive curricula

Education has been described as the process of preparing an individual to become a functional and acceptable member of society. Two concepts are inbuilt in the definition of education, namely creation of knowledge and experience; and growth and development thus signifying the importance of education in human development (Temu, 2003). According to Rudebjer *et al.* (2005) the institutions are responsible for curricular content, teaching materials and methods development and should have the delivery capacity to produce the graduates. Graduates so produced influence how society does agriculture. The experiences of society should feed back into the teaching process in order to produce the required product. Therefore, unless tertiary agricultural education is able to respond to societal changes and expectations, society will have difficulties understanding the roles of tertiary agricultural education. Given the challenges currently being faced by smallholder farmers in SSA, what changes then should be instituted in the curricula of tertiary agricultural institutions? The next section looks at curricula changes which might be necessary to ensure that the graduate being produced in the tertiary agricultural institutions is relevant for the task at hand.

Table 34.1. Current issues concerning tertiary agricultural education

Seminar	Objectives	Findings
SEMCIT, August 1999, Salzburg, Austria	To identify how sustainable development is affected by globalisation and its consequences and the role of education in sustainable development	Weak management of institutions Weak flow of information from university to communities Need for universities to serve as change agents Need for the establishment of sustainable funding mechanisms
SEMCIT, August 2000, EARTH, Costa Rica	To share and discuss the educational philosophy upon which EARTH University has based its innovative academic programme, and to explore its relevance for other countries in the tropics	Concentrated effort to improve entrepreneurial skills and thinking, social awareness through community outreach and real life experiences gained through work experiences and the internship program Holistic approach having underlying principles on which the curriculum has been designed including sustainable practices, experiential learning, close student-faculty interactions Quality time to interact through both formal and informal encounters
SEMCIT, May 2002, Jinja, Uganda	Assess the status of tertiary agricultural education in Africa and the urgency for making new paradigms operational in Africa	Many of the programs of tertiary higher education in agricultural and natural resources are not effectively meeting the challenges facing society Needs to enhance the capacity of universities to respond to society's changing needs, making agriculture more economically competitive, socially responsible and environmentally sustainable in an increasingly globalised world economy and able to provide effective contributions to food security and poverty reduction strategies Innovative changes were already taking place in tertiary institutions and it was important that these must be accelerated and reinforced. There is a need to develop new innovative learning methods in student-centred learning and effective cross-institutional sharing of lessons.
SEMCIT, September 2002, Chiang Mai, Maejo University, Thailand	To analyse the challenges confronting Asian agriculture and to examine the ability of innovative educational models to provide a means for sustainable development	Participants noted that there is an urgent need for change in agricultural higher education in Asia so that graduates can better contribute to sustainable development and poverty alleviation in the Asian tropics There was a need to change the curricular and develop more efficient networking, resource sharing and partnerships There is a need for documentation and dissemination of innovations and good practices in agricultural higher education in the region Transformation of existing university systems, including governance, admission practices, university finance and management systems and faculty development Creation of a new regional institution

SEMCIT, 2003, Norway	To present the findings and conclusions of the seminar process	There is a need to reverse the deterioration of the natural resource base and the continued impoverishment of the tropical regions. A transformation in agricultural higher education is required The transformation must be able to educate young leaders with the skills, knowledge and mindset that will enable them to transform the agricultural sector—making it more sustainable, more able to provide employment and capital to regional economies and more responsive to the needs of the rural populations Three-pronged approach was advocated for: i. transforming existing institutions, ii. Creating new regional institutions which will serve as incubators or catalysts of change in the regions and iii. networking. iii. networking.
April, 2003, Kenya, ANAFE symposium	Building agricultural and natural resources education in Africa: Quality and relevance of tertiary education	There is inadequate agricultural and natural resource sector development and there are shortfalls in content and delivery of these disciplines at colleges and universities There is inadequate financial support of tertiary educational institutions Most of the people doing farming in SSA are either uneducated or have at most primary education There is a need to improve the curricular content and delivery to make it locally relevant There is a need to link tertiary agricultural education (TAE) with rural and agri-industry development objectives There is a need to improve the teaching and learning capacity, methods and use of technologies There is a need to address the plight of women and youth There is a need to foster inter-institutional and regional collaboration
April 2007, RUFORUM Symposium, Malawi	Building scientific and technical capacity through graduate training and agricultural research in African Universities	Recognised that there is a disconnect between agricultural education and training (AET) and equipping the students with practical skills; inadequate integration of research, teaching and community outreach in the University systems; coordination of AET by different government ministries and dissonance in expectations from AET by the stakeholders Selection of agricultural students is not based on interest or passion for agriculture Noted that the agricultural curricula does not allow for rapid responses to the changing market needs that affect agriculture; HIV/AIDS, globalization, climate change, international trade, sustainable rural development and NRM. There is a need to emphasise training that leads to greater impact on community development and instil in students a strong system of ethics and a passion to serve society Sensitise and lobby governments to provide supportive policy, infrastructural framework and adequate budget Need for the rationalization and modernization of curricula

		and pedagogy Need to develop faculty retooling and retraining programmes Encourage and foster functional partnerships with clearly defined conceptual and structural frameworks. Institute policies to motivate and provide incentives to faculty for involvement in outreach activities.

Climate change

Tertiary Agricultural Education (TAE) institutions must work closely with advanced research institutions and Universities in the North to generate different scenarios and possible mitigating effects. Such scenarios must be part of teaching and learning as well as graduate research.

Biotechnology

Biotechnology refers to any technique that uses living organisms to make or modify a product, to improve plants or animals or to develop microorganisms for specific uses. Modern Biotechnology innovations offer wide scope for making substantial impact on crop production.

For example in crop improvement, biotechnology has been used extensively to develop crops that are resistant to pests and diseases, eliminating the need for farmers to use expensive pesticides. Biotechnology has also been used to develop crop cultivars that are drought tolerant, able to utilise water more efficiently and are more tolerant to moisture stress. It has also been used extensively to develop crops that are herbicide tolerant and that allow the use of broad-spectrum herbicides without being harmed. Biotechnology can play a major role in breeding for more nutritious crops (for example those rich in vitamin A). The general strategy of breeding more nutritious staple food crops holds great potential for reducing diseases caused by micronutrient deficiencies, such as iron, vitamin A and zinc deficiency, particularly in SSA.

These positive features make it imperative to tailor our curricula to address biotechnology issues. This technology will provide more options for our graduates particularly when they have to provide the right environment to be able to grow new crops.

Information and communication technology

The discovery of computers has revolutionised the way information is obtained, produced, managed, disseminated, accessed and controlled. They have largely changed the way we work and play. Information is considered to be the most valuable single resource in the world today.

Availability of timely, relevant and accurate information is known to make a difference between the success and failure of projects and profit and loss for business organisations. The linkage between computers and telephones has produced electronic mail and Internet. These two are revolutionising communication and information access throughout the world. So pervasive is the role of information technology that the world is now said to be in the information age. Bill Gates, the Microsoft Co-founder, has predicted that the first 10 years of the 21st century will be "the digital decade" where information will be accessed almost everywhere.

Everywhere in the world information technology is regarded as an essential resource for efficient running of various activities. This is more so for a graduate who would want to try out new crop production. Data on the crop pertaining to growing conditions, processing and marketing can easily be obtained by typing a few key words into the Internet search engine.

Dramatic changes will occur in the agricultural production/distribution system in the near future driven by advances in IT. This technology will be critical not only for improving efficiencies but also for providing a competitive advantage. Due to this increased value of information and the increasing role of private sector in providing it, the issue of proprietary nature of and access to information will become more complex. Since information provides a competitive advantage, the exchange of some information could be reduced. An expected output of these technological improvements is that there will be higher returns to investments in human capital and research and development.

Students in the Faculties of Agriculture and Natural Resources in SSA need to acquire advanced computer skills on how computers can be applied to research, planning and analysis. They also need to know how computers and information technology can be applied at farmer level. The opportunities that information technology can offer are enormous indeed. It is imperative, therefore that all Faculty of Agriculture and Natural Resources graduates be computer literate.

Agroforestry

Agroforestry as a new field of science is gaining widespread promotion owing to the many benefits accruing from its use. These benefits include wood and wood products, human and animal food, socio-economic benefits, soil conservation and fertility, *ex situ* conservation of germplasm and many environmental services. Given the many facets of agroforestry, this course presents a student with the challenge to think more broadly on crop production by assessing different relationships: competition, complementarity, and facilitation. This will provide a student with methods of evaluating and managing interactions for optimum benefits in crop production.

Given the loss of soil fertility through mining occurring in SSA (Rosegrant *et al.,* 2005) owing to the fragile nature of the ecosystem and since people are poor and cannot afford inorganic fertilisers agroforestry has the potential for improving soil fertility for sustained crop production. Agricultural students need to learn how to apply the principles of agroforestry to its full advantage.

Agroforestry is now expanding and is covering areas including domestication of indigenous fruits; value addition and marketing of hitherto ignored fruits. Agricultural students need to be alert as they view world trends and chart on new ways and new crops, which they can grow to enter regional and world markets for income generation.

Post-harvest technologies

Emphasis on increasing food production in the past focused more attention on the production side through use of improved seed varieties, fertilisers and pesticides and improved husbandry practices than on post-harvest handling, processing and storage. However, such efforts did not yield the expected results as a result of high post-harvest losses. Such losses affect weight, quality, nutrition value and market value.

Some estimates suggest that in developing countries as much as a ¼ to a ⅓ of the total crop yield may be lost as a result of inefficiencies in the post-harvest systems. Even if production now shifts to alternative crops, the same emphasis will be given. Agricultural students need to understand how they can tackle issues pertaining to post-harvest losses so that they can avoid and minimise losses to themselves and to the farming community they might be advising.

Agro-processing, especially small-scale food processing, offers tremendous opportunities for development in SSA. It provides income to entrepreneurs, through value addition, and creates job opportunities particularly for the rural poor. These industries also generally improve the quality of the raw material and reduce post-harvest losses. Processing can also increase the variety and choice of foods available to a given community. This whole area of the post-harvest chain requires well-trained personnel, and hence should be considered a key component or our curriculum.

Irrigation and water management

Globally, agriculture accounts for about 69 % of all water use. The quantity of fresh water that is continually renewed through the global water cycle is a finite natural resource. Water is and will continue to be an increasingly critical constraint in much of Africa. Therefore Irrigation and water management are areas that will need to be given top priority in our training programmes. According to the United Nations Food and Agriculture Organisation, 30 to 40 % of worldwide food production comes from an estimated 260 million ha of irrigated lands, one-sixth of the world's farmland. In SSA only 0.3 % of 346 000 ha is under irrigation. Harnessing irrigation potential in SSA will ensure that graduating students can venture into the production of crops which hitherto were not being grown in the country. Irrigated farms also produce 50-200 % higher yields for most crops. Irrigated farmlands are also inherently more productive than rain fed farming systems.

It is not only the harnessing of irrigation that is critical; the method of irrigation itself is important for the sustainable use of the technology. With most of SSA already experiencing water shortages due to climate change, the way to go will be to adopt low cost methods of irrigation for improved integrated water management. Applying precise amounts of water to crops at optimum times and in the proper quantities can greatly lower water use in irrigation without necessarily lowering food production. This will also improve water quality, since it will minimise excess run-off of irrigation water into streams. The reduction of runoff from irrigation can also reduce salinity, soil degradation and groundwater contamination.

Irrigation technology has advanced tremendously in the areas of water use efficiency and productivity, integrated water resources management and small-scale irrigation technology. Exposure of all agricultural students to these technologies would definitely produce a better graduate capable of optimising the use of limited water resource for alternative crop production in SSA.

Conclusions

Sub-Saharan African countries will continue to battle with inadequate food provision for its people and remain a net food importer. The situation is being worsened by climate change. The agricultural graduates, who should be the main drivers of change are still being trained in the researcher-extension-adaptation-adoption mode and lack the capacity necessary to champion the change necessary to tackle impending challenges, for example climate change. There is a need to develop tertiary agricultural curricula that will ensure that the graduates produced are able to understand climate change issues, world food production trends, target niche markets for wealth generation and employment creation and serve as the major change agents in sustainable agricultural production. They can champion this if they undertake courses such as entrepreneurship skills, information and communication technologies, irrigation and water management, biotechnology, post-harvest technology, and agroforestry.

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35. Building Local Skills and Knowledge for Food Production: Empowering Poor Fisher-folks in Sub-Saharan Africa

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Abstract

Fisheries and aquaculture make important contributions to livelihoods, national economic development and regional food security in sub-Saharan Africa. Expanding this growth and ensuring that it is following a sustainable pathway that will yield benefits for many more farmers, businesses and consumers is a development priority for the sector. While progress has been achieved in many places, these experiences are often not fully documented and disseminated effectively to the rest of the region where they could have positive impact. In many countries of Africa, donor funds that have been spent over the last 40 years have not enabled the communities in any way to strengthen their ability to cope with natural disasters and chronic food deficits. Countries across the developing world are stunted not only by physical constraints like drought or desertification, but also by a lack of skilled individuals and effective organizations that can help lift these countries from poverty to prosperity. Without this human and institutional capacity, many developing countries have difficulty making the best use of resources they have and implementing policies that could help their poorest people. This paper examines the need to build local skills and indigenous knowledge for effective and sustainable fisheries production in sub-Saharan Africa. The paper presents the facts that building capacity for food security involves enhancing the ability of individuals, groups, organizations, and communities to sustainably meet their food and nutrition security challenges. It highlights the need to develop skilled, creative, and motivated individuals among stakeholders of different categories. It advocates for the establishment of effective regional, state and local institutions, both governmental and non-governmental, to engage people in problem solving. The paper suggests among others, the fostering of teamwork among farmers, extension agents, and scientists among different government ministries and nations. The paper advocates for donor commitment to bankroll initiatives that offer tangible paybacks.

Key words: local skills, indigenous knowledge, fisher folks, fish production, sub-Saharan Africa

Introduction

The fish sector makes a vital contribution in meeting the food and nutrition security needs of 200 million Africans and at the same time provides income for over 10 million people that are engaged in the production, processing and trade in this industry (Tables 35.1 and 35.2). In recent times fish has become a leading export commodity in Africa and globally with an annual export value of US $ 2.7bn (Chimatiro, 2007). Throughout Africa, the occurrence of a large number of inland or freshwater lakes, rivers and other aquatic habitats such as swamps and floodplains, of different sizes and forms, and containing a wide variety of fish populations, have provided mankind with the opportunity to exploit fish for food, income and livelihoods in general for many centuries. Fish, fishing and fisheries are an integral part of the culture and economy of many peoples and countries in Africa, with significant historical linkages which provide an important back-drop to more recent fisheries development programmes pursued by national governments.

Table 35.1. Total and per capita food fish supply by continent in 2003

	Total food supply (million tonnes live weight equivalent)	**Per capita food supply (kg/year)**
World	104.1	16.5
Africa	7.0	8.2
North and Central America	9.4	18.6
South America	3.1	8.7
Asia (including China)	69.4	40.1
Europe	14.5	19.9
Oceania	0.8	23.5

Source: FAO (2007)

Table 35.2: World fishers and fish farmers by continent **('000)**

Total	**Year**				
	1990	**1995**	**2000**	**2003**	**2004**
Africa	1,832	1,950	2,981	2,870	2,852
North and Central America	760	777	891	841	864
South America	730	704	706	689	700
Asia	23,736	28,096	34,103	36,189	36,281
Europe	626	466	766	653	656
Oceania	55	52	49	50	54
World	27,737	32,045	39,495	41,293	41,408
Of which fish farmers					
Africa	3	14	83	117	117
North and Central America	3	6	75	62	64
South America	66	213	194	193	194
Asia	3,738	5,986	8,374	10,155	10,837
Europe	20	27	30	68	73
Oceania	1	1	5	5	4
World	3,832	6,245	8,762	10,599	11,289

Source: FAO (2007)

Overall, today, it is estimated that the inland fisheries of Africa produce 2.1 million tonnes of fish, which represents 24 % of the total global production from inland waters (FAO, 2004). In comparison to marine fisheries, inland fisheries production is relatively small, representing only 6 % of global production. In Africa, marine fisheries production (4.7 million tonnes) is also much larger compared to inland fisheries (2.1 million tonnes). However, this simple comparison of gross production between marine and inland fisheries can be misleading, for it can be shown that inland fisheries in Africa generate a wide variety of benefits (such as income and food) and underpin the livelihoods of millions of people. This is the case in many countries because inland fisheries are diverse and widely distributed, they can be exploited quite easily using simple technologies, and are often well-integrated with farming and other economic activities.

However, there are concerns that inland fisheries in Africa are increasingly under threat from factors such as environmental change (both man-made and natural) and overexploitation (due to over-fishing). There is also widespread recognition at all levels of society and government that measures need to be taken to safeguard the flow of benefits from inland fisheries. An important first step must be for all stakeholders to build a common and strategic understanding of the importance of inland fisheries for Africa, and to reach a consensus on how to address the main challenges through various strategic investments. This paper examines the need to build local skills and knowledge for effective and sustainable fisheries production in sub-Saharan Africa. The paper presents the facts that building capacity for food security involves enhancing the ability of individuals, groups, organizations, and communities to sustainably meet their food and nutrition security challenges.

Fisherfolks and fish food production in Africa

Inland fisheries in Africa are largely non-industrial (artisanal) in nature, including the sub-sectors of catching, processing, transportation, trade and gear manufacture, which are quite distinct occupations. In parts of Africa, fishing is a part-time activity for rural people who also tend to farm, keep animals and engage in other economic activities (Figure 35.1). Fishing is often well-integrated within the overall pattern of work for rural households and communities, with well-established patterns of input and time allocation. Many inland fisheries are also a part of local culture and tradition, and based on local knowledge of fish resources and migrations, the use of a variety of different fishing technologies to suit particular fishing opportunities and seasonal changes in flood regimes, for example (Akegbejo-Samsons, 1995).

Inland fisheries are important for food security in many African countries for a number of reasons (relating mainly to supply and entitlements). First, there is a ready and year-round supply of fish because of the widespread distribution of diverse water bodies – fish can often be caught quite easily using relatively simple gears which are operated by men, women and children. Second, many water bodies and fisheries are operated as common pool resources or open access resources (where there are no restrictions at all) – this means all members of the local community can exploit the fisheries resources according to their needs (of course, in many situations, fisheries can become overexploited, or access is restricted by the enforcement of user-rights by the 'owners'). Third, in many rural and urban areas, fish is the cheap alternative to other more expensive sources of animal protein (meat, eggs). Fourth, fish is often available in markets because of the well-developed formal and informal fish trade in Africa. Fifth, fishing is often integrated with farming, and provides a source of food and income (to purchase food) during seasons when farm produce might not be available to eat or sell.

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Fisherfolks and other participants in the management of small-scale fisheries in developing countries apparently face a critical dilemma. The concern to alleviate poverty among people with current or potential access to fish stocks and the response to the apparent crisis in world fisheries are severely limited. Poverty alleviation is now high on the agenda of most developing-country fishery management agencies and their partners in donor and multilateral institutions. 'Sustaining livelihoods' of the poor in fishing-dependent communities by enabling or enhancing their access to fishing opportunities is prominent in contemporary fisheries development thinking. This appears to be fundamentally incompatible with the current imperative to reduce capacity and to create more effective barriers to entry to fisheries, in order to conserve fully overexploited fish stocks.

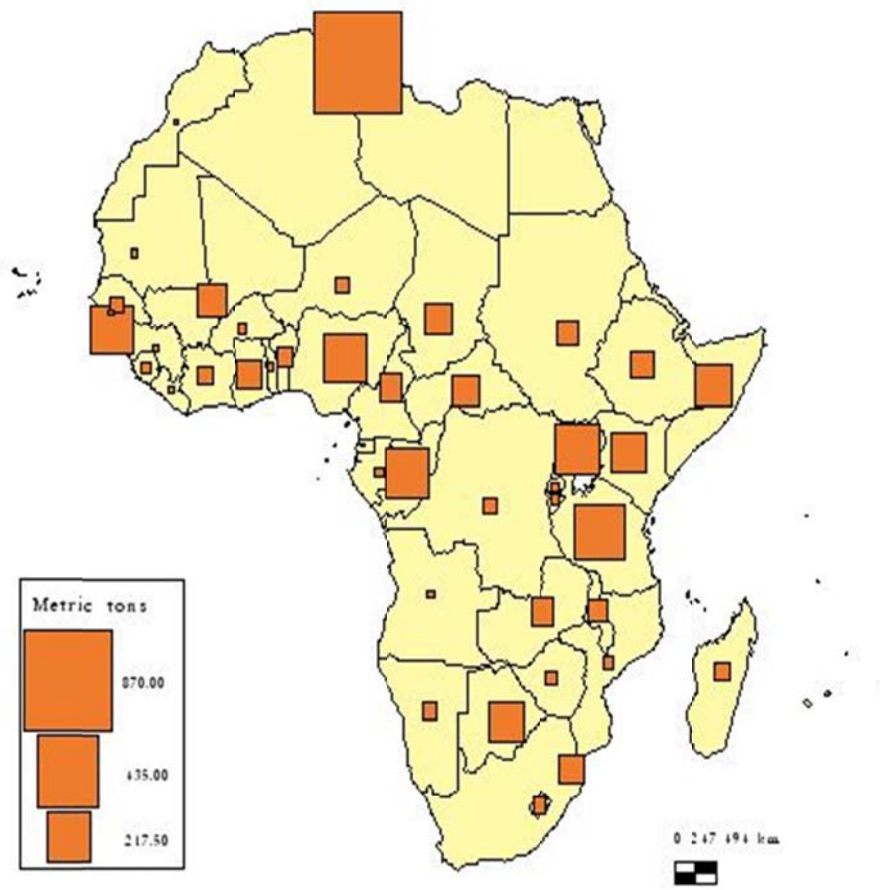

Figure 35.1. Inland fisheries production by country in Africa (2002) (Source: FAO FishStat)

Status of local skills and indigenous knowledge in African fisheries sector

There is no standard definition of local skills and indigenous knowledge (IK). However there is a general, understanding as to what constitutes local skills and IK (Adedipe *et al.,* 2005). In Africa, it could variously be regarded as ethno-science, folk knowledge, traditional knowledge, people's knowledge among others. Perhaps a very profound definition is given by Warren (1987) as local knowledge that is unique to a given culture and society. In the view of Rajasekaran (1993), IK is the systematic body of knowledge acquired by local people through the accumulation of experience, informal experiences and intimate understanding of the environment in a given culture.

Fisherfolks are increasingly involved in decision-making, often in partnership with local or national government agencies. This 'co-management' often requires fisher folk to manage legal rights, be involved in the creation of by-laws governing fishing activities, allocate user-rights, administer licensing schemes and participate in the monitoring and assessment of the fishery. These tasks call on a variety of literacy and numeracy skills, and, if fisher folks are to benefit from newly-acquired rights, also require confidence in interacting with bureaucracies and the judiciary on equal terms. At present, too few fisher folks have such levels of literacy, thereby limiting the extent to which they benefit from a shift towards rights-based fishing. Current socio-psychological opinion is of the view that what modern science and technologies would need to do is to continue to find ways and means of accommodating and using multi-dimensional framework of IK (Adedipe *et al.,* 2005). Various research studies in different parts of Africa show that the fishermen are adequately equipped with local skills and indigenous knowledge to facilitate sustainable fish production and management. All that seems to be required is well packaged and effectively organized 'modules' by the different governing bodies responsible for fisheries management in the region (World Bank, 1984; Allsopp, 1985; Neiland, 2004).

Capacity building and indigenous knowledge enhancement

Various attempts aimed at capacity building and knowledge enhancement in the fisheries sector has been made in the various African countries. Organizations like New Partnership for African Development (NEPAD) and their partners recognize the importance of science, technology and innovations (ST and I) in development and have agreed on a number of priorities for research, capacity strengthening and information dissemination as can be seen from the NEPAD Action Plan for the Development of African Fisheries and Aquaculture and the Regional Stakeholder Consultation. Priorities and Research coordination in support of the AU/NEPAD Action Plan for the Development of African Fisheries and Aquaculture were advocated. These priorities include the following: (a) the need for Sub-regional Research Organizations (SROs) to mainstream fisheries and aquaculture within their programmes; (b) the formulation of regional research agendas to allow countries to jointly address generic problems; (c) a review of curricula at all levels of training to focus on development priorities in fisheries and aquaculture; and, (d) information dissemination to make use of all available regional and local networks.

Improved human resource capacity is imperative for sustainable fisheries and aquaculture development as good quality human resources will trigger the development of more efficient technologies, legislations and management plans. In order to enhance cross-learning and sharing of practical science, technologies and innovations by fishers, fish farmers, extension agents, researchers and policy-makers, innovation platforms must be created at all levels, including local, national and regional levels. In Nigeria, for example, Ladu *et al*. (2004) presented the approaches of the Nigerian-German (GTZ) Kainji Lake Fisheries Promotion Project. It showed the importance of the use of communication for development in research and extension in the fisheries sector. This project operated from 1993-2002 with the aim of sustainable fisheries management to improve the standard of living of fishing communities. Components included a community-based fisheries management plan, information system, extension system and environmental management (hyacinth control). Early actions included extension communication activities, workshops and village meetings with fishers and their leaders – to promote understanding, generate awareness and promote co-operation between actors. Establishment of a regular radio broadcast (3 times/week) prepared in cooperation with fishers. Support from other local leaders also is important. Demonstration and extension of fish processing technologies and alternative activities (fruit, Soya beans). Variety of media: newsletters, posters, drama group. There are good indications that the ideas and approaches presented have been adopted at community level and by other actors, and that fisheries management will improve into the future.

Knowledge Management and Capacity Building in the Fisheries Sector

Although knowledge management, like fisheries management, covers a vast area of practice and study, there is a general agreement that knowledge management is an approach to organizational management that includes certain basic elements. These elements are: recognition of the critical role of knowledge in furthering organizational goals, an effort to develop some conceptualization of the knowledge for that particular context, utilization of at least one of the basic quartet of knowledge management processes, and the belief that the organization will derive some benefit from the knowledge management approach. There is also an understanding that technology will further any or all of the knowledge management processes (Collins, 2006)

In its report, NEPAD listed a comprehensive sectoral perspective that will be required, involving agents and processes at a range of levels, in a range of production regimes, together with a well-informed strategy for investment, human development, social inclusion and environmental acceptability. These approaches are tailored towards capacity building in the fisheries sector.
Suggested key elements of this strategy include:

1) Critical appraisal of existing and emerging systems, sectoral elements and trends. This will assess features and trends in investment, markets, efficiency, productivity and benefit at both farm and sectoral level and identify opportunities to enhance the financial, social and environmental benefits. The aim will be to identify both the opportunities for growth and productivity change in major production systems and zones, and the means by which previously constrained areas may be able to share the benefits of the sector.
2) Analysis of mechanisms of change towards desired outcomes. Sector-wide review of urban-rural dynamics of resource access, market demand, employment and food supply, and assess legal, institutional and other barriers. The comparative roles of artisanal and commercial producers, options for promoting rural enterprise at a range of positions within the value chain, clarifying how development processes can be positively tuned to meet needs of poorer households and communities, and identifying practical strategies and policies for investment and scale-up from best practice will also be assessed. Running through these studies will be a focus on identifying who benefits and how, and what can be done to increase these benefits to the Campaign's target groups.
3) Engagement of public, private and third sector (e.g. NGOs) agents in targeted strategies to achieve growth and efficiency aims. These strategies will seek to improve seed (fish) supply quality and diversity, system management, feeding, and risk management (culture fisheries).They will work through participatory and technical research processes that will be managed to foster an active, knowledge-rich development environment, that will facilitate rapid and comprehensive uptake of improved strategies.
4) Establishment of a broader framework for sectoral development. This will be pursued at local, national and regional levels, to achieve effective interactions with other resource users, production sectors and institutional agents, and place aquaculture and its benefits positively and sustainably within the broader social and economic context. Key processes to engage will include water and land use planning, community support, resource access and co-management, economic development and trade strategies, ecosystem protection and enhancement, and mitigative geo-management (NEPAD, 2005).

Building local skills and encouraging indigenous knowledge, where do we start from?

There is no doubt that the African fisher folks are endowed with local skills and indigenous knowledge which have been used effectively over the years. In other to translate these skills to sustainable adoption and economic uses, different government agencies in the continent need to do more than we are currently doing. Just like agriculture, fish production systems (aquaculture and artisanal) can be categorised into three distinct areas. First, industrial fish production, characterised by large fish farm units and huge access to the wild with high capitalization and high input-independent; second, Up-coming new generation, characterised by a mixture of small and large fish farms and water concession which exploit varieties of fish species in cultured and non-cultured environments; and third, low resource or resource-poor fisheries, characterised by small farm units and poor fisher folks that meander through rivers, creeks and coastal waters. It is this third category that most fisheries practitioners belong in Africa.

In order to build local skills and encourage indigenous knowledge in Africa, the following suggestions are recommended for application:

(a) The literacy and numeracy factor among the fisher folks:

Increasing the literacy level of stakeholders in the fish sector is very vital in Africa. Literacy is a key aspect of human development with important benefits for people's livelihoods and capabilities, influencing their ability to access information and resources and to manage change. The literacy and numeracy abilities of fishing communities play a significant role in the management of aquatic resources as well as in the maintenance and diversification of livelihoods. Literacy and numeracy are integral to the livelihoods of many small-scale fishing communities. Uses include practices of record keeping, communication, management of business activities and marketing. These activities may typically involve book keeping, using both literacy and numeracy, and letter writing as part of long distance trade (FAO, 2006).

Literacy is also increasingly needed as part of community management of fishing resources and in environmental protection activities. The ability to access and use written communication influences decision-making (for example on health or credit) which can also enhance and diversify people's livelihoods.

Effective literacy and numeracy skills and practices are integral to fisheries management, environmental conservation, common property management and livelihoods diversification. Many of these activities involve complex texts and practices. Community development activities such as microfinance also require the mastering of complex literacy and numeracy tasks. Such tasks in fishing communities imply meeting conditions quite unlike that of most conventional literacy programmes in order to be task-oriented, flexible and responsive to the diversity of people's expressed needs and aspirations. Fishing communities often suffer from educational disadvantages due to geographical and social marginalization. Education providers are often unable, or unwilling, to provide services tailored to mobile and migratory populations which include many fisher folk. The educational status of parents also plays an important role in deciding to send children to school and in their ability to support their children's education.

(b) Putting the traditional knowledge of the fisher folks into scientific use:

Traditional techniques are still very much prevalent in many African countries, despite gradual changes in fisheries practices over the years. Fishers' knowledge is seen in all steps of fish production, harvesting, handling or processing, marketing and consumption. Central to this is the learning system. Folklore, which serves as one of the channels along which knowledge can flow to future generations, is rich in beliefs, customs and practices, in many communities. Information is usually transferred orally in stories and song related to experiences of daily life. Fishing is thus learnt informally, as is common with the livelihoods of rural communities, and passed on to subsequent generations through practice. Nsiku (2003) exposed this traditional instinct and its usefulness in Malawi.

He observed that local fishers have detailed knowledge of fish types in their area, fishing methods and gears, as well as how to interpret climate and other factors such as wind, rain, clouds, temperature, vegetation and animal life to determine suitable times and places to fish. Similarities or large differences in fish are appropriately distinguished through assigning names to individual or group(s) of species. Other factors that fishers use to predict whether or not fishing will be successful include fish movements or migrations, feeding areas and times, breeding seasons and colours, and predator-prey relationships. Fish ecology is thus learned, although not in a scientific sense or methodology. Fish utilization tended to correspond to the level of prevailing techniques of fishing, he concluded.

(c) The place of beliefs, customs and practices in fishery resource management

Customs, beliefs and practices also have a big role to play in fish food production in Africa. For example, GOM/UN (1992) states that "*…For the majority of rural based Malawians, traditional value systems still influence and guide their day to day life..."* For the management of natural resources, the current situation is very different. Conservation of fish resources has become important to local fishers and other players in the fisheries industry (Sen and Nielsen, 1996; Scholz *et al.,* 1998). African beliefs and customs play a very major role in resource use especially in the fishery sector where the traditional cloak of adherence to beliefs is very difficult to break. Taboos and deified rules are strictly kept by the people in the fishery. This has helped to maintain resource balance in many African countries, especially among fishermen (GOM/UN 1992). The fish ecology and geo-climatic and other resource knowledge of fishers, which has been accumulated through traditional practices over centuries (Hoole, 1955; Msiska, 1991; Matowanyika, 1994), has to be used in ways that are cognizant of current realities of life and protect fish resources from depletion. Africans cannot afford to discard these beliefs under the platform of civilization.

(d) Effective application of the principles of Sustainable Livelihoods Approach (SLA)

The SLA has its origins in studies concerned with understanding the differential capability of rural fisher folks to cope with crises such as droughts, floods, or plant and animal pests and diseases (Chambers and Conway, 1992). The approach also borrows ideas from an ecological literature concerned with the sustainability of ecosystems or agro-ecological systems. The concepts of resilience and sensitivity as livelihood attributes also originate in this context. Resilience refers to the ability of an ecological or livelihood system to “bounce back” from stress or shocks; while sensitivity refers to the magnitude of a system's response to an external disturbance (Allison and Horemans, 2006). It follows from these ideas that the most robust livelihood system is one displaying high resilience and low sensitivity; while the most vulnerable displays low resilience and high sensitivity. The concept of ‘a livelihood’ seeks to bring together the critical factors that affect the vulnerability or strength of individual or family survival strategies. Understanding how people succeed or fail in sustaining their livelihoods in the face of shocks, trends and seasonality can help to design policies and interventions to assist peoples' existing coping and adaptive strategies. These interventions may include, at various levels, social service provision, insurance and compensation payments and promotion of diversification- all issues seldom considered by fisheries management and policy analysts (Allison and Horemans, 2006).

The SLA is now widely used by development agencies and NGOs to achieve a better understanding of the scope for development intervention in support of natural resource management systems (Ashley and Carney, 1999; Figure 35.2). The Food and Agriculture Organization (FAO) of the United Nations, the UNDP and other international non-government organizations such as CARE, OXFAM and most of the European bilateral agencies have recently put these principles into their development practice and recognize that, taken together, they represent a new way of working. A fundamental precept of the approach is that it seeks “to identify what [people] have rather than what they do not have” and “[to] strengthen people's own inventive solutions, rather than substitute for, block or undermine them” (Moser, 1998). This alone serves to distinguish it from many past fishery development approaches! The livelihoods approach is utilized in different ways, according to the goal of the study or programme. In development practice, it is often used as a ‘process’ tool to enable participants in development programmes who come from different sectors (e.g. local government, business development, health, transport, natural resources) to work together to identify key constraints and opportunities for development intervention (Ashley and Carney, 1999). The SLA is also widely used as a project and programme design framework. Management programmes or development projects can be re-focused on sustaining livelihoods by appropriate definition of their aims and objectives, the means of verifying achievement of these objectives and indicators for monitoring progress. In Africa, steps towards identifying resilience and sensitivity levels among the different ecological environment of our fisher folks should be of paramount importance in this period of climate change.

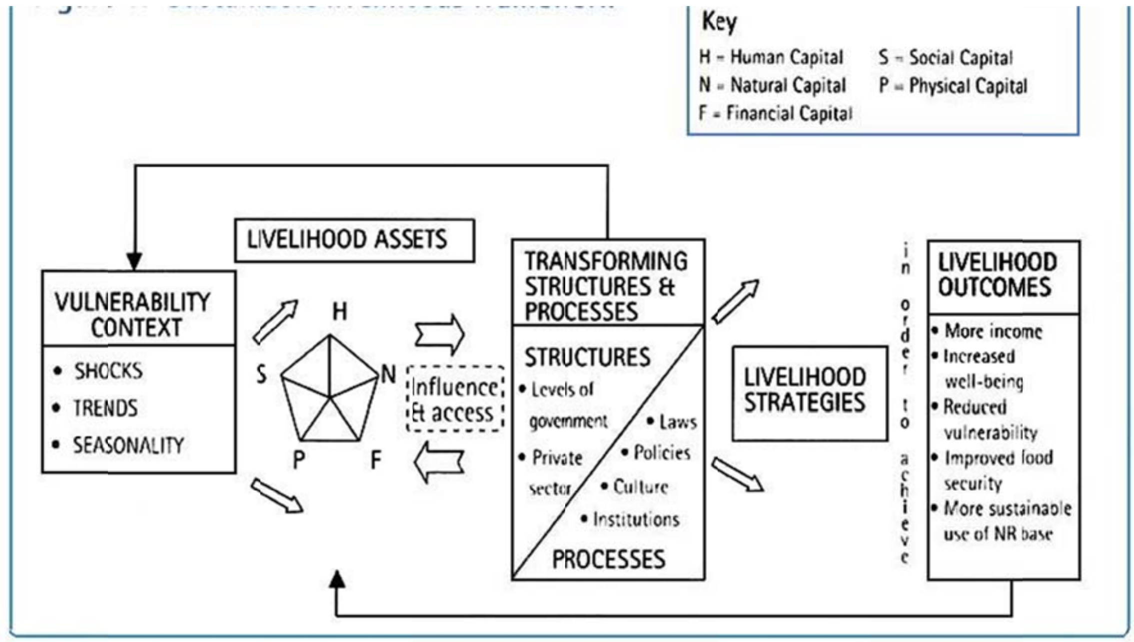

Figure 35.2. Sustainable livelihoods framework

(e) Effective use of Fishermen's Cooperatives and Organizations

The fisheries sector plays a major role in the freshwater and marine water ecosystems of the developing countries, where artisanal fisheries supply the bulk of the fish consumed by both inland and onshore dwellers. Artisanal fisheries include some of the poorest and most neglected communities within the society for, without land, such communities often find themselves outside mainstream economic and political life. For example, over 5 million fishermen are employed either full or part-time, in small-scale or artisanal fisheries across the coastal length of Nigeria (Akegbejo-Samsons, 1995). They are located in remote areas hence often cut off from formalized extension services which are available to other agricultural groups. The low level of fish production through aquaculture and the hazardous nature of wild harvesting are attributed to a number of constraints, the major one being inadequate provision of information to would-be farmers and the paucity of guides to existing ones. With little or no knowledge of the status of the different aquatic fauna, the average fish farmer and fisherman is ill-equipped for successful and sustainable production.

Akegbejo-Samsons (2007) revealed that if these fisher folks are organized into Cooperative groups and contact organizations, their production level could be doubled in quantity. Fishermen cooperatives have great roles to play in building local skills and knowledge. These include: (a) collective access to loans, grants and donor assistance; (b) collective bargaining power in case of disputes; (c) collective access to extension materials and subject matter specialists.

(f) Empowering actors with information

In Africa, there has been an increase in socio-economic and poverty-related research on fisheries in recent years. This has helped to broaden our understanding of the nature of poverty in fishing communities, and to broaden (and in some ways re-define) the approaches which are used for fisheries development. African fisheries make vital contributions to food and nutrition security of 200 million people and provide income for over 10 million engaged in fish production, processing and trade. Understanding poverty in fishing communities and the means to address it, therefore requires a good understanding of social structures, social relations and politics (all essential elements of governance), as well as patterns of change, with particular reference to entitlements (Neiland *et al.,* 2005). Governments and industries need reliable statistics in order to understand the economic relationships within the fisheries sector and its linkages to other sectors, e.g. finance, energy supply or vessel construction. Communities need catch and effort statistics if they are to achieve and ensure a fair and appropriate distribution of benefits. Policy-makers need such statistics so that fishing communities can be properly represented when sectoral policies are being developed. Information is the key to power in addressing food and nutrition security. Information relevant to food and nutrition security needs to be accessible to civil society and the media, not only to government. Information must include analyses (and appropriately simplified communication of related results) on causes and effects of food and nutrition insecurity and likely outcomes of policy changes and public investments. Continuous education in food and nutrition security should be part of the empowerment process. As farmers' organizations are strengthened and empowered, due consideration should be given to those organizations that serve fishermen and fish farmers. According to Kiplang'at (2003), conventional communication channels such as radio, video and television have been used successfully in Africa to communicate agricultural information, but these have been monologue and have not allowed for much interaction with users. There are still problems and constraints on what can be done to bridge the information gaps between the fisher folks and government agencies. Not much has been done to evaluate the effectiveness or impact of some of these operational information strategies. Our governments can improve on these aspects for effective and sustainable fish production.

(g) Priorities for research and capacity building

According to Chimatiro (2007), forty-two percent of the African research institutions are weak in fisheries and aquaculture, leading to a lack of a common and strategic understanding of the challenges being faced by the sector and the importance of fisheries and aquaculture research for development. Three major factors have been identified as constraint to capacity building, research and development, namely insufficient funds, lack of core research staff and weak research infrastructure (FAO, 2006). There is also a general lack of scientific capacity to undertake stock assessment to generate new knowledge for managing fisheries. Africa needs to deploy more resources into education and training of fisheries scientists and for building effective linkages between education and research institutions so that the scientific and academic community can be more attuned to the needs of the sector. Senior decision-makers and planners would be better able to guide decision-making if there was adequate scientific data on the fisheries and aquaculture sector. Key priorities include planning and management of fisheries resources, fisheries post-harvest management, processing and marketing, development of standards, the expansion of the aquaculture sector in Africa, and trade and export of fisheries. It is expected that donor countries can assist in the areas of training and fisheries management.

Science-based, long-term management plans are key to properly regulated and sustainably harvested marine and inland fisheries resources. Such management plans are needed in Africa and should take into account the trans-boundary nature of fish stock and the migratory feature of many fishing communities. Capacity needs to be strengthened at national and regional level in order to generate the data and transfer of information and knowledge on science, technology and innovations (ST and I) across regional borders, as well as for policy development.

Using ICT to improve production in the fish sector

In the agricultural sector, Information and Communication Technology (ICT) applications are being promoted to facilitate wide access to information, and intensive sharing of knowledge. ICTs can also be used to build the capacities of farmers through distance education and lifelong learning programs. Access to information and training will allow farmers to learn new techniques in order to raise their productivity. In addition, geographic information systems (GIS) which combines information on soils, hydro-geology, rainfall with socioeconomic data allows for early warning. The use of ICT in the fishery sector will advance the power of fisher folks to produce more at sustainable level. The following areas that require the use of ICT include: (a) Fish site (farm) selection, survey and demarcation; (b) Fish pond construction and management; (c) Fish species selection for rearing; (d) Fish seed multiplication, rearing and procurement; (e) Fish feed formulation and appropriate application; (f) Market information dissemination; (g) Farmer-to-farmer extension services; (h) Adoption of information and Technology transfer; (i) Climate change and climate-related information exchange (Akegbejo-Samsons, 2007).

The mode of service will include the following:

(a) Provision of video, documentations and documentaries on the different aspects of fisheries production;
(b) Production of training manuals and technical information;
(c) Radio programmes;
(d) Television (TV) recorded programme;
(e) Printing of technical handbooks, brochures, leaflets, posters, magazines and farmers' bulletins;
(f) Use of Internet, Email and Electronic soft and hard wares to reach prospective fish farmers and fishermen.

The potential role of ICTs in Aquaculture/ Fishery is envisaged to cover, (a) Pluralist information flows can be enhanced through the use of ICTs among the fisher folks; (b) New ICT will complement the conventional information delivery service between the various stakeholders in the sector; (c) It will offer vast information storage, fast and inexpensive communication channels and links between fishermen and fish farmers. Other projects in which ICTs are being used to facilitate sustainability and food security in Africa include the United Nations Development Program's Sustainable Development Networking Project (SNDP) (Mansell, 1998) , The Ghana Agricultural Information Network System (GAINS) (Opoku-Mensah, 1999) , Business Intelligent Trade Point in Burkina Faso, and UNEPnet of the United Nations Environmental Program(Lal *et al.,* 1999) .

Conclusion and Recommendations

This paper has shown that the African fisher folks are endowed with local skills and indigenous knowledge which have been used effectively over the years. It also shows that in other to translate these skills to sustainable adoption and economic uses, different government agencies in the continent need to do more than we are currently doing. Our experiences from various pro-poor projects across Africa show that rural knowledge centres, especially those based on ICTs, have high potential to bridge the information and knowledge gap between urban and rural areas. Building capacity for food security involves enhancing the ability of individuals, groups, organizations, and communities to sustainably meet their food and nutrition security challenges. The need to develop skilled, creative, and motivated individuals among stakeholders of different categories cannot be overemphasized in the African continent. By linking with providers of information and other essential services such as credit, agro-inputs and transporters of commodities many of whom are located in urban areas, fish food production can be greatly enhanced in Africa. Indeed if the World Bank assertion that a one per cent increase in agricultural growth leads to an increase in the incomes of the poorest by twice as much as the same investment in the service sector (Peacock, 2004), is something to go by then most of the points highlighted in this paper have important roles to play and should be promoted. Additional effort is required to test and validate the strategies presented here under different environments/scenarios and to ensure that the progress made towards developing appropriate mechanisms for empowering the poor fisher folks of the continent. Achieving fisheries/agricultural development in Africa will require promoting and scaling-up of 'good practices' among all stakeholders. Networking among knowledge centres in order to share resources and experiences is also important.

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36. Promotion of Environmental Legislation and Sustainable Environmental Management By Tertiary Institutions In Zimbabwe

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Abstract

Zimbabwe has a relatively well developed environmental policy and institutional framework as well as legislation and structures for training on sustainable wetland utilization, management and protection. This paper provides a review of what tertiary institutions are contributing towards offering curricular and training in environmental studies related to wetlands. Issues of wetlands and biodiversity management covered are indicated and discussed together with ways by which the various institutions can improve quality of training and also develop relevant research programs for staff motivation and retention. The study shows that the potential that this system provides, however, is being threatened by a number of limitations due to poorly coordinated legislation, lack of incentive in tertiary education system coupled with lack of adequate and meaningful research funding in wetland ecosystems. It was concluded that wetlands in Zimbabwe, being among some of the most complex ecosystems where water is the primary factor controlling the environment and the associated biodiversity must be utilized sustainably. Research and development in tertiary institutions must therefore be supported in order to produce competent graduates and also establish a body of knowledge and recommendations best suited for wetland ecosystem utilisation and biodiversity management.

Key words: Legislation, tertiary institutions wetland management

Introduction

Wetlands form an important component of the granite landscape. This is part of a well-developed vegetation-soil catena ecosystem which takes the form of upland crests to lowland vleis mainly comprising woody species such as of *Brachystegia* and *Julbernardia* in well drained upland sites; *Burkea africana*, *Parinari curatellifolia* and *Terminalia sericea* in the middle slopes that are imperfectly well drained and *Hyperrhenia, Loudetia, Sporobolus* grass species and sedges in the lowland vleis with heavy soils that are poorly drained and aerated where most tree species would not normally grow (Zhou, 2004). These are areas where water is the primary factor controlling the environment and the associated plant and animal life (Matiza and Crafter, 1994).

In Zimbabwe, these areas cover about 1.28 million ha of which 25 % are found in communal areas (Owen *et al.,* 1995). For their management and protection, there is a relatively comprehensive environmental legislation called the Environmental Management Act (EMA) [*Chapter 20:27*] as well as institutional frameworks and division of responsibility for promoting and enforcing good conservation practices in these wetland areas at all levels; from local to central government although there are obvious constraints such as institutional overlaps and shortage of operational resources (Ministry of Environment and Tourism, 2003).

Since independence in Zimbabwe, there has been a significant increase in the number of tertiary institutions supportive of legislation and policy on environmental issues and agriculture. Of all the existing universities at least 60 % offer curricula on environmental or natural resources, agricultural and other related disciplines in addition to a number of other tertiary institutions mainly agricultural colleges and related institutions, for example forestry and wildlife colleges.

The objective of this paper is to review the environmental legislation in place since independence in 1980 and the major roles of tertiary institutions in promotion legislation for sustainable agricultural use and environmental protection in wetlands by smallholder farmers in the semi-arid areas of Zimbabwe.

Materials and Methods

This paper is based on reviews and consultations with various sectors and institutions involved in higher learning, environmental management, legislation and policy that have a bearing on wetland use and protection in the semi-arid areas of Zimbabwe. Sources of information include the Environmental Management Act [*Chapter 20:27*] and the Environmental Management (Environmental Impact Assessment and Ecosystems Protection) Regulations contained in the Statutory Instrument (SI) 7 of 2007 (Zimbabwe Government, 2003).

Results and conclusions from previous legislation and policy studies including hydrological studies that provide important information for developing and promoting sustainable legislation and policy formulation in communal areas wetland protection is much needed, were also utilized.

Results

Role of teacher training colleges in curriculum and promoting of environmental legislation and policy

Results from this study reveal that teacher training colleges have played a very vital role in developing curricula and promoting legislation and policy by creating awareness and access to use and protection of wetlands in the education system. For primary school education, curriculum has been developed to include a syllabus on a combination of issues that include environmental, social, agricultural, forestry, wildlife and fisheries. Although this syllabi do not contain specific issues of wetlands and wetlands management, they try to ensure that aspects of wetlands utilization taught especially under topics on gardening and vegetable production with good “hands on approaches ” land management practices so as to develop manipulative skills in learners and create awareness and positive attitudes to foster positive interest towards environmental legislation, management and protection at an early stage in the education system. Curriculum in environmental studies and agriculture at this level therefore were based on an essential body of knowledge of the environment and other areas which can arouse the interest of learners so that they acquire the necessary concepts, skills and attitudes for environmental management and protection in future.

Agricultural college curriculum on environmental management

The Ministry of Agriculture through the Department of Agricultural Education is responsible for all agricultural education and extension training at a number agricultural colleges country wide such as Mlezu, Esigodini, Chibero, Kushinga Phikelela, Rio Tinto, Gwebi and BlackFordby while the Department of Agricultural Research and Extension (AREX) is responsible for all agricultural research and extension dissemination including offering in-service training to all officers in the field on relevant courses for wetland management that include air photo interpretation, veld management, land use planning and soil conservation. Officers in turn will be expected to cascade technical knowledge and advice to farmers and communities involved in wetland utilization, management and protection. Since agriculture has a direct impact on environment, government policy therefore reflects the need for environmentally sustainable production especially semi-arid areas where wetland utilization and management are of paramount importance for example in Lower-Gweru district and Gutu district of the Midlands and Masvingo Provinces, respectively. In addition, AREX also plays a coordinating role for young farmers and farmers clubs or groups in income generating projects such as sustainable wetland gardening and protection in an environmentally friendly manner.

Environmental Institutions and legislation in Zimbabwe

A number of governmental and non-governmental environmental institutions such as Environmental Management Agency (EMA). Forestry Company of Zimbabwe, ZERO, ENDA-Zimbabwe, Zimbabwe Environmental Law Association are involved in the promotion of environmental legislation and policy formulation in Zimbabwe. The Ministry of Environment and Tourism (MET) is responsible for coordination mainly through the EMA, Parks and Wildlife Authority and the Forestry Company of Zimbabwe. Of these three institutions, EMA is the main institution responsible for the implementation of wetland management in addition to a range of other environmental management functions it is mandated to do. As the main custodian regulating the use of these wetlands, one of EMA's objectives is to enforce legislation and implement policy to achieve sustainable utilization and protection of these ecosystems. There are many educational awareness and publicity programmes for wetland protection and management that have been planned, implemented and monitored by EMA in collaboration with other governmental and non-governmental organization (NGO's) institutions, local authorities and communities and schools. In addition to these, similar to AREX, Forestry Company of Zimbabwe and Parks and Wildlife Authority, EMA plays an important role by offering in service training to build and strengthen capacity of its staff to perform various functions. Such in-service course programmes would include techniques in wetland identification and classification, resource assessment, local environmental action planning, geographic information systems (GIS), remote sensing (RS) applications and Project Planning and Implementation.

While many training programmes have been and continue to be implemented, EMA, which is still in its infancy, is not yet fully equipped with adequate professionally qualified staff to effectively carry out some of the planned programmes. More qualified staff however, are being recruited to close this gap but the staff turnover rate appears to be excessive due to problems of poor motivation, shortage of facilities and thin budgetary allocations. Besides, transport shortage is a major challenge to EMA's development and capacity to implement its environmental management programmes countrywide.

State and private university institutions and environmental legislation

The contribution of tertiary institutions towards promoting environmental legislation and policy in the country has mainly been in design of curricula, teaching and awareness creation. A number of state and private universities such as Midlands State University Bindura State University, NUST and Africa University do offer curriculum on environmental studies, natural resource management and agriculture although without specific reference to wetland ecology, management, and protection.

From details of environmental education and related curricula reviewed, the major issues that are covered on wetlands include their identification and geographical distribution, utilization and management, the latter especially through integrated or community based approaches. At Midlands State University these aspects are covered in the Department of Geography and Environmental Studies, and Departments of Land and Water Resources Management, Agriculture and natural Resources Management.

The main delivery mechanisms include lessons or lectures, seminars, practicals, guided tours and field trips. Occasionally resource persons are invited to give specialist presentations on specific aspects of management not necessarily for wetlands. Of late, at many state and other private universities, e-Learning has become one of the most fashionable ways by which to a large extent part-time as well as parallel and visiting for students on part-time, parallel and visiting degree programmes countrywide.

Discussion

In Zimbabwe, wetland cultivation has been on the increase in both communal and resettlement areas to cope with the effects of climate change and frequent droughts leading to their degradation. Poor land management such as poor ploughing practice that causes gullies and mono cropping that causes breakdown of organic matter and instability of the soil (Whitlow, 1983) are the main causes of degradation.

There is no curricula designed to address the issue of wetlands. Existing curricula in teacher training colleges aims at developing positive attitudes towards agriculture and natural resource conservation. Although the syllabus does not cover specific aspects of wetlands, however, it includes a wide range of topics some of which relate to wetland ecosystems and their management. Examples of such topics are Agro-ecological zones and types of agriculture activities, veld management, stream bank cultivation, fish farming, water and legislation (Mutimba undated).

The issue of sustainable utilization and management of wetlands is regulated by the existing Environmental Management Agency Act (EMA) Act [*Chapter 20:17*] which among other things, sets out provisions for sustainable management of natural resources and protection of the environment; the prevention of pollution and environmental degradation and the preparation of a National Environmental Plan (NEP) and other plans for the management and protection of the environment in Zimbabwe (Government of Zimbabwe, 2003). Prior to the enactment of this act (EMA Act *[CAP 20:27]*), there was a wide range of legal instruments or legislation aimed at environmental conservation and natural resource management. These include the Natural Resources Act *[Chapter 20:13]*; the Atmospheric Pollution Prevention Act *[Chapter 20:03]* the

Hazardous Substances and Articles Act [*Chapter 15:05*] and Noxious Weeds Act [Chapter 19:07] (Ministry of Environment and Tourism, 2003). Originally, the Water Act of 1927 that was amended in 1976 regulated the use of all wetlands (WSMS, 2000) together with the Stream Bank Protection Regulation of 1952 (Owen *et al*., 1995).

Many of these pieces of legislation were inherited from the colonial period when conservation was perceived by people in former tribal trust lands (TTL`s) as a restrictive approach to land use, an image that has still remained in communal, resettlement and even in commercial and urban areas up to the present day (Chenge *et al*., 1998) . Because of the fragmentary nature of the legislation, there were conflicts between some of the acts with certain laws not equally applicable to different categories of land, provisions for being neither applicable to, nor enforceable, for example in communal areas where environmental problems were most serious (Moyo *et al*., 1993).

Recent studies on the analysis of policies, strategies, curricula and institutional arrangements for wetland management in Zimbabwe (IUCN, 2007) shows that while a comprehensive legislation on environment and natural resources exists, there is no legislation for wetlands *per se*. The regulations for protection of wetlands laid down in the existing act are not clear and as a result do not give sufficient detail as to what they are and how they are defined and characterized. In addition, there are no guidelines to be followed by other institutions involved in promoting legislation. There appears to be a shortage of significant research work to address legislation and policy issues particularly in terms of looking at coordination of existing legislation and environmental policy and its effectiveness on sustainable wetland management and utilization especially in rural areas.

A number of initiatives by EMA in collaboration with local authorities and communities through local environmental action planning (LEAPS) have been initiated. Much of this work has been based on current non-empirical information and indigenous knowledge on wetland utilization and management. Future programmes are therefore suggested to augment existing wetland management information through systematic scientific research processes, trials and demonstrations that are aimed to promote enforcement and policy for sustainable conservation and management of wetlands.

While the objectives of the curriculum is partly to create awareness and consciousness, of policies and guidelines for environmental protection, its content must provide practical skills and knowledge for sustainable environmental management but the content of courses at national tertiary institutions still remains theoretical due to lack of facilities, financial research resources and availability of suitably qualified lecturers. This is one of the greatest present day challenges facing curricula delivery systems in most institutions in Zimbabwe.

Conclusions and Recommendations

Since independence in 1980 in Zimbabwe, there has been an increase in the number of universities and other tertiary institutions offering curricula in environmental issues and agriculture. However, not much has been done so far about legislation and policy by universities in terms of how these (legislation and policy on environmental issues) could be improved to make them more effective in influencing environmental management and protection in

Zimbabwe. This has been mainly due to many constraints related to shortage of facilities, inadequate funding and lack of motivation. It is therefore recommended that more support in the form of resources and facilities must be allocated by government to academic institutions together with various other institutions involved in wetland management to create a conducive environment for promoting legislation, planning and implementing wetland management projects.

Universities have a great challenge to enhance research capabilities for staff in the Environmental Management Agency (EMA), which is the implementing agency of all environmental legislation. This can be achieved by developing more oriented in-service research training for staff to acquire skills and techniques in database development and analysis. Databases on wetlands (that is presently lacking) must form the foundation for their (wetlands) classification, for further research and development of curricula as well as for management guidelines that must be followed by all other institutions involved in wetland utilization, management and protection.

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37. The Status of Agro-Forestry Education in Cameroon's Agricultural Training Institutions: Case study of the Regional College of Agriculture, Bambili

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Abstract

The main objective of this paper was to develop a common Agro-Forestry curriculum for the Three Regional Colleges of Agriculture of the Ministry of Agriculture and Rural Development (MINADER) in Cameroon**.** To achieve this, we organized a survey which enabled us to visit Agricultural Training Institutions (ATI) and examine their present curricula. Also visited were the Forestry School and some Veterinary and Zoo Technical Schools. Discussions and interviews were held with School authorities, trainers, former trainees and professional organizations/institutions using these graduates. Also different syllabuses/ curricula were analyzed to appreciate their contents. The results obtained reveal that despite the amount of money spent on Agro-Forestry (AF) education and extension in Cameroon and the huge potential of these institutions coupled with the enthusiasm of the trainees to acquire knowledge in this domain, policy makers are still not interested in convening a forum of experts which will look at some of these problems that militate against the development of a curriculum and to discuss new attitudes towards the said AF Education. Policy makers are therefore still to find their feet to identify a philosophy and goals to help plan and develop a new curriculum for ATI. Furthermore, there is still a big gap between rhetoric and practical actions. Research and professional opinions carried out by different parties on this topic have shown that apart from the ignorance and difficulties met by farmers in the field, there is the lack of extension staff and lack of interest on the part of policy makers to initiate and encourage the personnel of Agro-Forestry and Agricultural Training Institutions especially the teaching staff for further training. The paper ends by proposing strategies for the introduction of AF Education in all ATI of Cameroon to upgrade their status with a focus on "Mainstreaming climate change into Agricultural Education".

Key words: Agricultural Training Institutions, Agro-Forestry Education, interest, Regional College of Agriculture Bambili, Cameroon

Introduction

Agricultural Education in Cameroon is managed by the Ministry of Agriculture and Rural Development (MINADER). Throughout the country there are eighteen (18) training institutions of Agriculture among which are three (3) Regional Colleges of Agriculture (RCA) that train Agricultural Technicians and Senior Agricultural Technicians at intermediate level. RCA Bambili, Bamenda in the North West Province of Cameroon is one of these institutions and it is a member of ANAFE since 2001. Graduating students from these institutions are awarded diplomas equivalent to National and Higher National Diplomas respectively after a 2-year course programme.

Agroforestry Education is a programme set up by the World Agro-Forestry Centre (ICRAF) for awareness creation and sensitization of the population worldwide on sustainable management of natural resources and environment. In the framework of its training and educational programme called "the African Network for Agriculture, Agroforestry and Natural Resources Education" (ANAFE) and, with the new orientation and policy of this training programme known today as "Building Africa's Scientific and Institutional Capacity" (BASIC), there is an urgent need for all the stakeholders to embark on the new approach with a global view of the challenges facing the Universities and colleges. Furthermore, looking at the rate at which Agroforestry in other parts of the World is evolving with a new theory into research, there is therefore a need to develop new theories in our planning and development programmes.

This paper seeks to (i) examine the curriculum contents of Agricultural Training Institutions (ATI) of Cameroon and their potentialities, (ii) determine the training gaps, problems and constraints and, (iii) propose recommendations and solutions that may help to address the problems. It further argues that a new approach with a focus on sustainable management of natural resources and environment should be incorporated into production and marketing. In view of improving the quality of entrepreneurship orientation Agro-Forestry and Agricultural Education and training should also focus on entrepreneurship skills development. Sustainable management here entails taking into consideration notions of climate change in all aspects and forms of Agricultural and Agroforestry education practices in each agro-ecological zone.

Three broad sets of solutions are envisaged based on differing analyses of possible causes of reluctance of policy makers, inadequacy of school curricula and challenges of a rapidly evolving world. One set of the solution focuses on the availability and possibilities of extending demonstration plots in each institution. The second set is that policy makers should understand the use and the need of reviewing and updating the curriculum of ATI which was planned and developed some decades ago with the focus of training civil servants. And lastly, the prescription that past and similar curricula exist in school libraries and other organizations from which inspiration can be drawn by curriculum planners and developers.

Resources and Method used

Site of the Study

In Cameroon, professional schools and other educational training institutions at the intermediate level are oriented towards the training of government extension workers hence the development of the rural sector is shared at this level among the Ministries of Livestock, Fisheries and Animal Industries (MINEPIA), Environment and Nature Protection (MINEP), Forestry and Wildlife (MINFOF) and Agriculture and Rural Development (MINADER).

Training institutions of these Ministries are well-distributed throughout the country according to the agro-ecological zone. As such, each of the five Agro-Ecological Zones that describe Cameroon as defined by the Institute of Agronomic Research for Development (IRAD) has at least one of these training institutions (See Map of Cameroon Figure 37.1). These agro-ecological zones are the Sudano-Sahelian, Humid Tropical Forest, Humid Equatorial Forest, High Savannah and the Western Highlands Zones. The training institutions recruit and train nationals and foreign students on government and privately sponsored basis for a 2-year programme at intermediate level. Upon graduation, the trainees are awarded Certificates or Diplomas of Assistant Technicians, Technicians and Senior Technicians in Veterinary, Animal Science and Fisheries, Elementary Forestry and Wildlife and General Agriculture respectively.

Methodology

From 1996 to 1999, we organized, a survey which enabled us to visit the two other Regional Colleges of Maroua and Ebolowa, and the Technical Schools of Agriculture, Kambe in the North West Province, Bafang in the West, Dibombari in Littoral and Sangmelima in the South. Specialized Training Schools for Community Development in Santa, North West Province, Kumba in South West, National Cooperative Colleges, Bamenda, the Forestry School in Mbalmayo and, the Veterinary and Zoo-Technical Schools in Jakiri (North west) and Foumban (West Province) were also visited. We also held discussions and interviews with 12 School authorities, 18 trainers, 124 former trainees and 8 professional organizations/institutions (MIDENO, UCCAO, private poultry and piggeries farms, SBM-Nyombé) employing these graduates. We analyzed the different syllabuses/ curricula to appreciate their contents. We limited ourselves to these few numbers of institutions and organizations because of the lack of sponsorship to go further.

Results Obtained

A brief overview of the different subjects offered in the institutions showed that although they included other components (crops, trees and/or animals, water and air) in their specific curriculum of education and training, their concerted efforts and collaboration towards promoting an integrated system of education is not present. Our focus here will be the Agricultural Training Institutions (ATI) with a case study of the Regional College of Agriculture, Bambili in the Western Highlands Zone.

A - Weak points.

In Cameroon, people attend educational or professional training institutions so that on graduation they can get a job in government, para-statals and private organizations and not for self-employment.

The vision of the Government at the creation of these institutions was to promote agricultural activities at the farmer's level to ensure food security through the training of front line extension staff. With the population growth and the economic crisis of the late 1980's, the current vision is to train privately sponsored personnel who upon graduation will settle on their own as business entrepreneurs.

Figure 37.1. The map of Cameroon showing the five agro ecological zones

The present curriculum of Cameroonian Agricultural Training Institutions (ATI) was designed and developed in 1980 and has never been reviewed. Thus this curriculum is cannot take into account the new orientation of the present world economy. It does not respond to today's job market which is oriented towards self-employment and the high demand of professionals in industrial plantations and in civil societies. Tables 37.1 to 37.8 present the course contents for cycles C, B1 and B2 offered in the country. The curriculum of the national zootechnical and veterinary school is shown in Tables 37.9 and 37.10.

The technical course contents of Forestry for Technicians and Senior Technicians cycles does not mention the word "Agroforestry" for this programme was elaborated and adopted just 2 years after the introduction of Agroforestry in Cameroon that is around 1980 by the then Institute of Agronomic Research IRAD.

The official total credit hours allocated for the Forestry course is 10 hours for theory and 10 hours for practical work for each cycle. This does not enable full participation of the trainees in both theoretical and field practicals and demonstration work. However, this is much more relevant and functional in today's society. This situation has been observed through the behaviour of some former students and the employers of these graduates who mentioned that the graduates lacked practical knowledge and skills to become entrepreneurs with business oriented mind.

Many attempts at the individual and institutional levels to review the present curriculum of the Regional College of Agriculture, Bambili, Cameroon and to officially introduce for example Computer Science, Agroforestry, Introduction to Project Writing, have failed due to lack of interest from decision makers, curriculum planners, curriculum developers and curriculum agents in Agricultural and Agroforestry fields and the Ministry of Agriculture and Rural Development (MINADER).

Looking at the total students population at the lower, intermediate and advanced levels in the rural training institutions and the need for Forestry and Agroforestry development in the country, Forestry and Agroforestry subjects are being taught only in the Forestry School, Mbalmayo (Ministry of Forestry and Wildlife) in humid forest zone and the University of Dschang (Ministry of Higher Education) in Western Highlands zone which admits only a maximum of 150 forestry students a year.

The lack of incentives for staff, the lack of means for further research and the lack of grants for refresher courses have prevented young men and women from entering the teaching career. Therefore, in Regional College of Agriculture (RCA) Bambili as in many other rural training institutions, the youngest teaching staff member is 43 years old.

Those that were given scholarship around the 1990s to undertake BSc and/or MSc training course abroad have upon completion of their studies gone for greener pastures abroad or in Cameroon.

There is limited incentives like in-service training, refresher courses, travelling and duty post allowances, research grants and promotions. Apart from salaries, lecturers have no allowances and incentives as in other professional and educational training institutions, like the Zootechnical and veterinary school of MINEPIA (Garoua, Jakiri, Foumban) which are also natural resource institutions and government teacher training colleges “Ecole Normale d’Instituteurs de l’Enseignement Général (ENIEG)” throughout the country.

Agricultural/Forestry engineers posted to RCA Bambili therefore do everything possible to be transferred to a different department of the same ministry or change ministry completely. There are limited openings for graduates from these schools to undertake degree courses in Agroforestry (AF). The two years Agroforestry course programme initiated by the University of Dschang and sponsored by the French Government graduated only 2 batches of students and was terminated (Source: Interview with former trainees).

In addition, there is lack of interest for youths, school leavers and graduates to write the competitive entrance examination into the ATI since government stopped recruiting in the public service in 1987. Those who have struggled and trained themselves are not reclassified by the Ministry of Public Service and the NGO communities in the country cannot employ all graduates. The global drive towards sustainable natural resources management which entails that developing countries embark on human capacity building and empowerment of local communities is lacking. The effects of HIV/AIDS and other epidemic diseases are equally not considered in the training of frontline staff in rural development as those who die are not replaced. Finally, there is the lack of concerted and coordinated efforts among stakeholders of AF education in the country.

Curriculum of the National Zootechnic and Veterinary School Jakiri, North West Province

The NZVS of Jakiri (Cattle), Foumban (Fisheries) and Garoua (Cattle, Fisheries) are natural resource institutions under the Ministry of Livestock, Fisheries and Animal Industries (MNEPIA)

As for the other curricula, the curriculum of the National Zootechnic and Veterinary Schools was elaborated in French and to avoid mis-translation of some technical words, we have maintained the French version.

Table 37.1: Regional College of Agriculture (CRA) = CYCLE B1

A) – First Year: 900 Hours

Code	Theme	Number of hours				Cf
		CT (1)	TD TP (1)	Stage	Total hours	
STA	Statistiques / **Statistics**	15	10		25	3
BIO	Biologie-Botanique, Physiologie végétale/ **Biology-Botany-Plant Physio**	15	10		25	3
GEN	Génétique / **Genetic**	12	8		20	2
ECO	Economie générale et rurale / **General and Rural Economy**	40	20		60	6
GES	Comptabilité / **Accounting**	40	20		60	6
CLI	Climatologie **/ Climatology**	8	6		14	2
AGR	Equilibre du sol et intervention de l'homme (géologie, pédagogie, fertilité et fertilisation, techniques culturales du sol, irrigation, assainissement, défense et restauration des sols) / **Soil Sciences**	100	40		140	14
A	Assolement et rotation / **Shift Cropping and Rotation**	15	5		20	2
AGR	Semences et semis / **Seeds and Sowing**	20	10		30	3
MAC	Machinisme / **Agricultural Mechanization**	40	20		60	6
TOC	Topographie et constructions rurales / **Survey and Rural Construction**	40	30		70	7
ELE	Elevage (zootechnique générale, sélection du bétail, alimentation des animaux domestiques, Agrostologie, zootechnie spéciale, zoohygiene)/ **Animal Sciences**	70	60		130	13
PI	Conduite parcelle individuelle et travaux pratiques sur la ferme/ **Individual Plots and Farm Practicals**		120		120	12
STO	Stage ouvrier /			56	56	6
	Conférences (foresterie, développement communautaire etc)/ **Conférences**		10		10	2
	Langues / **Language**	30			30	3
	Sport / **Sport**		30		30	3
	Conduite / **Conduct**					4
	TOTAL :	**445**	**399**	**56**	**900**	**97**

B) – 2nd Year: 870 hours

CODE		Number of hours				Cœf
		CT (1)	TD TP (1)	Stage	Total hours	
NUT	Nutrition humaine / **Human Nutrition**	10			10	1
GES	Gestion / **Management**	35	25		60	6
ADM	Pratiques administratives / **Administration**	13	13		26	3
SOC	Sociologie Rurale / **Rural Sociology**	20	20		40	4
VUL	Vulgarisation / **Agricultural Extension**	27	27		54	6
FOR	Foresterie / **Forestry**	10	10		20	2
AGRE	Principales cultures au Cameroun (Agriculture Spéciale, Technologie et Conditionnement) / **Main Crops of Cameroon**	60	40		100	10
AGR	Défense des cultures (zoologie générale, phytopathologie générale, phytopathologie spéciale, méthodes de lutte, entomologie spéciale)/ **Crop Protection**	40	30		70	7
PI	Conduite parcelle individuelle et travaux pratiques sur la ferme / **Individual Plots and Farm Practicals**		80		80	8
STP	Stage professionnel **/ Practical industrial Field Attachment**			250	250	25

STM	Stage monographie / **Monographic Study**			120	120	12
	Conférences **/ Conferences**		10		10	2
	Sports / **Sports**		30		30	3
	Conduite / **Conduct**					4
	TOTAL :	**215**	**285**	**370**		**93**
	Soit :			**Heures**		**%**
	Cours théoriques/ **Class room lectures**			**215**		**24,5**
	TP + TD					
	Stages/ **Field Attachments**					
	TOTAL :			**870**		**100**

(1) CT = Theoretical courses (1) TD = Laboratory work (1) TP = Practical work

Table 37.2: Regional College of Agriculture (CRA) = CYCLE B2

A) – First Year: 900 Hours

CODE	**Theme**	**Number of hours**				**Coef**
		CT (1)	**TD TP (1)**	**Stage**	**Total hours**	
MAT	Mathématiques **/ Mathematics**	15	10		25	3
STA	Statistiques **/ Statistics**	20	10		30	3
PHY	Physiques / **Physics**	15	10		25	3
BIO	Biologie, Botanique, Physiologie végétale/ **Biology,Botany, Plant Physiology**	20	10		30	3
GEN	Génétique **/ Genetics**	16	10		26	3
ECO	Economie générale et rurale / **General and Rural Economy**	35	15		50	5
CLI	Climatologie / **Climatology**	20	20		40	4
AGRA	Equilibre du sol et intervention de l'homme (géologie, pédagogie, fertilité et fertilisation techniques culturales du sol, irrigation, assainissement, défense et restauration des sols / **Soil Sciences**	80	60		140	14
AGRB	Assolement et rotation / **Shift Cropping and Rotation**	15	5		20	2
AGRC	Semences et semis / **Seeds and Sowing**	15	5		20	2
MAC	Machinisme / **Agricultural Mechanization**	40	20		60	6
TOC	Topographie et constructions rurales / **Survey and Rural Construction**	40	40		80	8
ELE	Elevage (zootechnique générale, sélection du bétail, alimentation des animaux domestiques, Agrostologie) / **Animal Sciences**	40	30		70	7
PI	Conduite parcelle individuelle et travaux pratiques sur la ferme/ **Individual Plots and Farm Practicals**		120		120	12
STO	Stage ouvrier			80	80	8
	Langues / **Language**	30			30	3
	Conférences / **conferences**		10		10	2
	Sport / **Sports**		30		30	3
	Conduite / **Conduct**					5
	TOTAL :	**409**	**411**	**80**	**900**	**98**

B) – 2nd year: 870 Hours

CODE	**Theme**	**Number of hours**				**Cœffi**
		CT (1)	**TD TP (1)**	**Stage**	**Total hours**	
NUT	Nutrition humaine / **Human Nutrition**	10			10	1
GES	Gestion / **Management**	25	15		40	4
ADM	Pratiques administratives / **Administration**	13	13		26	3
SOC	Sociologie Rurale / **Rural Sociology**	20	20		40	4
VUL	Vulgarisation/ **Agricultural Extension**	27	27		54	6
FOR	Foresterie / **Forestry**	10	10		20	2
AGRE	Principales cultures au Cameroun (agriculture spéciale, technologie	60	40		100	10

	et conditionnement)/ **Main Crops of Cameroon**					
AGR	Défense des cultures (zoologie générale, phytopathologie générale, phytopathologie spéciale, méthodes de lutte, entomologie spéciale) / **Crops Protection**	40	20		60	6
ELE	Elevage (zootechnique spéciale, zoohygiene)/ **Animal Sciences**		80		80	8
PI	Conduite parcelle individuelle et travaux pratiques sur la ferme / **Individual Plots and Farm Practicals**					
STM	Stage monographie / **Monographic field Study**			120	120	12
STIP	Stage professionnel / **Industrial Field Attachment**			230	230	23
	Conférences / **Conferences**		10		10	2
	Sports / **Sports**		30		30	3
	Conduite / **Conduct**					4
	TOTAL :	**235**	**285**	**350**	**870**	**93**
				Heures		**%**
	Cours théoriques / **Class room Lectures**			**235**		**27**
	TP + TD					
	Stages / **Field Attachements**					
	TOTAL :			**870**		**100**

(2) CT = Cours théoriques, (1) TD = Travaux diriges, (1) TP = Travaux pratiques

Table 37.3: Technical School of Agriculture (ETA) = CYCLE C

A) – First Year: 865 Hours

CODE	**Theme**	**Number of hours**				**Cœffi**
		CT (1)	**TD TP (1)**	**Stage**	**Total hours**	
MET	Méthode de travail / **Work Method**	6	9		15	2
MAT	Mathématiques **Mathematics**	25	15		40	4
STA	Statistiques **/ Statistics**	15	15		30	3
PHY	Physiques / Physics	20	10		30	3
CHI	Chimie **/ Chemistry**	20	10		30	3
BIO	Biologie, Botanique, Physiologie végétale/ **Biology, Botany, plant Physio**	30	30		60	6
GEN	Génétique **/ Genetic**	10	10		20	2
GEO	Géographie du Cameroun / **Cameroon's Geography**	10			10	1
LAN	Langue **/ Language**		25		25	3
AGRA	- Equilibre du sol et intervention de l'homme (pédagogie, techniques culturales du sol, semences et semis) / **Soil Sciences**	40	20		60	6
AGR	Agriculture spéciale / **Main Crops of Cameroon**	25	15		40	4
AGRD	Défense des cultures (phytopathologie générale) / **Crops Protection**	15	5		20	2
ELV	Elevage (morpho physiologie et zootechnie générale) / **Animal Sciences**	40	30		70	7
MAC	Machinisme agricole / **Agricultural Mechanization**	20	20		40	4
TOP	Topographie **/ Survey**	10	15		25	3
ECO	Economie rurale(Economie générale, rurale, crédit, coopération)/ **Rural Econ**	45	15		60	6
SOC	Sociologie rurale / **Rural Sociology**	8	12		20	2
SP	Sport / **Sports**		30		30	3
STO	Stage ouvrier **/ Practical Field Work**			80	80	8
PI	Parcelle individuelle **/ Individual Plot**		150		150	15
CON	Conférences **/ Conferences**		10		10	2
	Conduite / **Conduct**					4
	TOTAL :	**339**	**446**	**80**	**865**	**95**

B) – Second Year: 911 Hours

CODE	Theme	Number of hours				Cœffi
		CT (1)	**TD TP (1)**	**Stage**	**Total hours**	
LAN	Langue / **Language**		25		25	3
AGRA	Equilibre du sol et intervention de l'homme (irrigation et drainage) / **Irrigation and Drainage**	20	20		40	4
AGRE	Agriculture spéciale / **Main Crops of Cameroon**	55	15		70	7
AGRD	Défense des cultures (phytopathologie spéciale et Entomologie) / **Crops Protection**	20	10		30	3
FOR	Foresterie **/ Forestry**	14	6		20	2
ELV	Elevage (zootechnie générale) / **Animal Sciences**	25	20		45	5
NUT	Nutrition humaine **/ Human Nutrition**	10			10	1
TOC	Construction rurale / **Rural Construction**	14	6		20	2
VUL	Vulgarisation / **Extension**	14	46		60	6
ADM	Administration / **Administratio**n	6	9		15	2
GES	Gestion / **Management**	35	15		50	5
DC	Développement Communautaire / **Community Development**	16	4		20	2
SP	Sports **/ Sports**		30		30	3
PI	Parcelle individuelle / **Individual plot**		150		150	15
STM	Stage monographie / **Monographic Study**			136	136	12
STP	Stage professionnel / **Industrial Field Attachment**			180	180	18
CON	Conférences / **Conferences**		10		10	2
	Conduite / **Conduct**					4
	TOTAL :	**239**	**356**	**316**	**911**	**96**
				Heures		**%**
	Cours théoriques			239		26
	TP + TD					
	Stages					
	TOTAL :			**911**		**100**

Table 37.4: Technical content of the Agro forestry course in Regional Colleges of Agriculture

No	Topic	Coverage
1	Ecology and protection of the nature	a) Main factors governing plant biology - Climatic factors - Edaphic factors - Biologic factors b) The roles of these factors on plants c) The main vegetal formation in the tropic in general and Cameroon in particular d) Nature protection methods
2	Silviculture	a) Goal and importance of Silviculture b) Organizations in charge of the conception and execution of silvicultural activities c) Species used in afforestation - Regeneration in tick and dense forests - Afforestation in Savannah region

3	Pisciculture or Fish Farming	a) Goal and socio-economic importance of Pisciculture b) Biology of species used in Pisciculture c) Different types of Fish Pond d) Intensive Fish Farming
4	Forestry Legislation	a) Users rights (Non-permanent forests, communal forests, community forests, private forests,) b) Manual of Procedure for the attribution of forest exploitation license, authorization to exploit NTFPs. c) Rights and obligations of owners of exploitation licenses and authorizations d) Implementation of offences e) Hunting permits and authorization f) 6- Regulations relative to land legislation
5	Forest Exploitation	a) Economy of forest exploitation b) Localization of main operations of forest exploitation c) 3- Forest industries (Sawing, Ply wood, Carbonization, cellulose industries, etc)
6	Hunting and Protection of Wild life	a) Socio- economic and ecologic importance of fauna. b) Localization of main animal species c) 3- Fauna reserves and National parks
7	Hunting	

Table 37.5: School for the training of specialists in cooperation (EFSC) CYCLE=B
Summary of the two years of training

Educational themes and activities:	**Number of hours**		
Educational themes :	**1st year**	**2nd year**	**Total**
- Méthodes de travail / **Work Method**	15		15
- Coopération **/ Cooperation**	70	40	110
- Socio économie du développement / **Socio-economy of development**	50	30	80
- Législation coopérative / **Cooperative Law**	35	15	50
- Communication, éducation et formation/ **Communication, Education and training**	35	15	50
- Gestion/Aménagement / **Management**	140	-	140
* Comptabilité générale et financière, techniques bancaires / **General and Financial Accounting, Banking Techniques**	140140	- -	
* Comptabilité financière, analytique et fiscale/ **Financial, Analytic and Fiscal Accounting**	-	60	60
* Analyse financière et technico-économique, gestion prévisionnelle, commerciale et du personnel, contrôle budgétaire, contrôles internes et externes (« auditing »), etc / **Financial and Technico-economic Analysis, Provisional, commercial and personnel Management, Fiscal control and auditing**	-	190	190
- Mathématiques **/ Mathematics**	40	-	40
Statistiques / **Statistics**	30	-	30
Agriculture / **Agriculture**	30	-	30
Langues / **Languages**	30	25	55
Conférences, visites/Coop. Scolaire/ **Conferences, School Cooperative**	50	45	95
Sport/Entretien de l'école **/ Sports and cleaning of campus**	30	25	55
SOUS-TOTAL	**545**	**435**	**980**

Table 37.6: School for the training of specialists in cooperation (ESFC) , CYCLE C
Summary of the two years of training

Educational themes and activities	**Number of hours**		
Educational themes	**1st year**	**2nd year**	**Total**
- Méthodes de travail / **Work Method**	15	-	15
- Coopération / **Cooperation**	60	40	100
- Socio-économie du développement/ **Socio-Economy of Development**	40	30	70
- Législation coopérative / **Cooperative legislation**	35	15	50
- Communication, éducation et formation/ **Communication, Education and Training**	30	15	45
- Gestion/Aménagement / **Management** * Comptabilité générale et financière, techniques bancaires / **General and Financial Accounting, Banking Techniques**	150	-	150
* Comptabilité financière, analytique et fiscale/ **Financial, Analytic and Fiscal Accounting**	-	80	80
* Analyse financière et technico-économique, gestion prévisionnelle, commerciale et du personnel, contrôle budgétaire, contrôles internes et externes (« auditing »), etc / **Financial and Technico-economic Analysis, Provisional, commercial and personnel Management, Fiscal control and auditing**	-	170	170
- Mathématiques **/ Mathematics**	50	-	50
- Statistiques **/ Statistics**	35	-	35
- Agriculture / **Agriculture**	30	-	30
- Langues / **Language**	30	25	55
- Conférences/visites/Coop. Scolaire/ **Conferences, visits, School cooperative**	50	45	95
- Sport/Entretien de l'école**/ Sports and manual labour**	30	25	55
SOUS-TOTAL	**555**	**445**	**1.000**

Table 37.7: Community development specialists training school (EFSDC) , CYCLE B
Summary of the two years of training

Educational themes and activities:	**Number of hours**		
Educational themes :	**1st year**	**2nd year**	**Total**
- Méthodes de travail / **Work Method**	10	-	10
- Développement Communautaire (y compris le développement rural integre)/ **Community Development and Integrated Rural Development**	60	60	120
- Economie domestique / **Home Economy**	60	60	120
- Sociologie / **Sociology**	35	30	65
- Communication / **Communication**	40	25	65
- Principes pédagogiques et méthodes de vulgarisation en éducation/ **Pedagogic principles and Extension Methods**	40	25	65
- Leadership et dynamique de groupe/ **Leadership + group dynamics**	40	40	80
- Développement et économie agricoles/ **Development and Agricultural Economy**	30	30	60
- Administration et gestion / **Administration and Management**	30	25	55
- Planification et développement économiques**/ Plannification**	30	25	55

- Instruction civique et législation / **Civic Education and legislation**	25	25	50
- Jeunesse Animation / **Youth Animation**	20	20	40
- Coopérations et autres activités lucratives / **Cooperative and Income generation activities**	20	20	40
- Sport / **Sports**	20	20	40
- Langues (français/anglais) / **Language**	50	50	100
SOUS-TOTAL	**510**	**455**	**965**

Table 37.8: Community development specialits training school (EFSDC) , CYCLE C
Summary of the two years of training

	Educational themes and activities:	**Number of hours**		
		1st year	**2nd year**	**Total**
1	Méthodes de travail / **Work Method**	10	-	10
2	Développement et Economie domestique / **Home Economy and development**	74	61	135
3	Sociologie / Sociology	42	36	78
4	Communication / **Communication**	51	26	77
5	Principes pédagogiques et méthodes de vulgarisation en Education **/ Pedagogic Principles and Extension Methods**	50	25	75
6	Leadership et dynamique de groupe/ **leadership +Group Dynamiques**	51	36	87
7	Economie domestique / **Home Economy**	71	66	137
8	Agriculture/Elevage/Foresterie / **Agric, Animal sciences + Forestry**	30	35	65
9	Coopératives et autres activités lucratives/**Coop+ income generation**	20	25	45
10	Langues / Language	50	45	95
11	Instruction civique et législation / **Civic education+legislation**	25	30	55
12	Jeunesse Animation / **Youth animation**	40	35	75
13	Sport **/ Sports**	28	19	47
	SOUS-TOTAL	**532**	**439**	**971**

Table 37.9: Planification de la formation de Technicien d'Elevage / Planning of training for Livestock Technician (Cycle B and C)

A) – First Year

Course	**Theory**	**Practical**	**Total**	**Coefficient**
Mise au courant	4	8	12	-
Climatologie	10	-	10	1
Pédologie	10	-	10	1
Botanique	20	20	40	4
Sociologie de l'éleveur	20	-	20	2
Typologie	20	20	40	4
Anatomie – physiologie	40	20	60	6
Extérieur des animaux	20	20	40	4
Ethnologie	20	-	20	2
Ethologie	10	-	10	1
Manipulation des animaux	10	20	30	3
Infrastructures d'élevage	60	60	120	12

Production végétale	30	40	70	7
Agrostologie	40	40	80	8
Alimentation générale	60	20	80	8
Hygiène en élevage	20	30	50	5
Génétique	40	-	40	4
Economie générale	10	-	10	2
Economie rurale	30	-	30	4
Statistiques	30	-	30	3
Vulgarisation	10	20	30	3
Monographie	6	-	6	
Stage monographique	-	240	240	24
Total (en heure)	**540**	**578**	**1118**	**110**

B) – Second Year

Course	Theory	Practical	Total	Coefficient
Présentation de monographie	30	-	30	-
Zootechnie spéciale	180	60	240	24
Provende rie	20	40	60	6
Sémiologie	20	10	30	3
Pathologie générale et systématique	20	-	20	2
Pathologie spéciale	40	-	40	4
Thérapeutique	15	20	35	4
Interventions zootechniques	10	20	30	3
Prélèvement pour le laboratoire	10	10	20	2
Comptabilité d' entreprise	20	-	20	2
Gestion du personnel	10	-	10	1
Gestion du matériel	20	10	30	3
Pratiques administratives	10	-	10	1
Législation	10	-	10	1
Planification des projets	10	-	10	1
Mécanique élémentaire	15	30	45	5
Pratique à la ferme d'application	-	150	150	15
Production végétale (stage ouvrier	-	80	80	8
Stage en élevage	-	240	240	24
Evaluation finale	30	-	30	-
Total (en heures)	**470**	**670**	**1140**	**109**
Total de la filière (en heures)	**1010**	**1248**	**2258**	**219**

Table 37.10: Planification de la formation d'Infirmier Vétérinaire / Planning of Training for Veterinary Nurse (Cycle B and C)

A) – First Year

Course	Theory	Practical	Total	Coefficient
Mise au courent	4	8	12	-
Géographie - Topographie	10	6	16	2
Sociologie	15	-	15	2
Typologie	14	4	18	2

Zoologie	40	30	70	2
Anatomie - Physiologie	80	60	140	14
Extérieur des Animaux	20	20	40	4
Ethologie	10	-	10	1
Manipulations	4	10	14	2
Agrostologie	10	10	20	2
Alimentation	40	10	20	2
Hygiène en Elevage	20	10	30	3
Zootechnie Spéciale	60	20	80	8
Economie Générale	10	-	10	2
Economie Rurale	15	-	15	2
statistiques	30	-	30	2
Sémiologie	30	15	45	5
Pathologie Générale	20	-	20	2
Pathologie Systémique	40	-	40	4
Pharmacologie	30	-	30	3
Thérapeutique	10	30	40	4
Vulgarisation	10	20	30	3
Monographie	6	-	6	-
Clinique	2	118	120	12
Stage Monographique	-	240	240	24
Total	**530**	**611**	**1141**	**115**

B) – Second Year

Course	**Theory**	**Practical**	**Total**	**Coefficient**
Présentation Monographie	30	-	30	-
Microbiologie	30	10	40	4
Laboratoire	40	80	120	12
Diognostique Necropsique	8	10	18	2
Pathologie Contagieuse	40	-	40	4
Pathologie Parasitaire	40	-	40	4
Pathologie de la reproduction	20	20	40	4
Toxicologie	20	-	20	2
Pathologie Spéciale	60	-	60	6
Chirurgie	30	20	50	5
Obstétrique	10	10	20	2
Inspection Sanitaire Vétérinaire	40	60	100	10
Clinique	-	100	100	10
Clinique Mobile	-	75	75	8
Campagne de Vaccination	5	20	25	3
Comptabilité d'Entreprise	20	-	20	2
Gestion de Personnel	6	-	6	1
Gestion du Matériel	10	-	10	1
Gestion d'une Pharmacie	10	-	10	1
Pratique Administrative	10	-	10	1
Législation	10	-	10	1

Planification de Projet	10	-	10	1
Cours de Mécanique Elémentaire	8	12	20	2
Stage en Clinique Extérieur	-	240	240	24
Evaluation Finale	30	-	30	-
Total (en heures)	**487**	**657**	**1144**	**110**
Total de la Filière (en heures)	**1017**	**1268**	**2285**	**225**

N.B: - A calendar week is 30 hours of instruction.
- Internship durations are expressed in hours. 240 hours are therefore 8 weeks.
- Les coefficients sont proportionnels au nombre d'heures de la filière.

B - Strong points or potentialities

Regional College of Agriculture Bambili is situated some 15 km from the Bamenda city, the headquarters of the Mezam Division and that of the North West Province of Cameroon. It is located in a rural area with large land (25 ha) and therefore the possibility of setting up demonstration plots.

There is good electricity and telephone networks and a free source of water though not always potable. All these present good potential for educational activities, demonstration plots and field visits. The training infrastructure is capable of hosting two or three training seminars/workshops at once.

The college also has a good relationship with neighbouring institutions of education like the "Ecole Normale Supérieur" (ENS Annex Bambili), The National Polytechnique of Bambui, the Antenna of the University of Dschang in Bambili and the Institute of Agronomic Research for Development (IRAD, Bambui).

C- Training gaps

The college has instituted A/F as a separate course carrying 20 hours of classroom lectures and 10 hours for practical. This is still under the Subject matter of Forestry and they all carry coefficient Two (2) for a total number of 60 hours. This is not enough for a course which requires a lot of laboratory and field practical.

There is no harmonization in the introduction of new subjects. What RCA Bambili is doing and the way she is doing it is not official since the other twin sister institutions of Maroua and Ebolowa are not doing same. This situation at times brings discrepancies and problems to students during examinations which are national.

Modular training courses on Forestry and Agroforestry related topics like Bee-Farming and Fish-Farming as income generating activities for local farmers are not regularly organized and when this happens, there is no follow up due to lack of funds.

RCA Bambili lacks trained staff in Forestry and Agroforestry. The only forestry technician who was transferred there on secondment in October 1985 to teach Forestry turned down the appointment just some few months after and went back to his Ministry, the then Ministry of Forestry in April 1986. He complained of not having incentives in the school as compared to what they usually have in their Ministry (risk allowance, uniform and gun allowances) or as poaching controllers.

The author of this paper like the rest of academic staff is an agronomist whom in the course of his studies has taken Forestry and Agroforestry as part of his courses. He has only developed a lot of interest through seminars/workshops but has never attended pure or refresher courses in these domains.

Among the other members of staff in RCA Bambili, the youngest one graduated from the Faculty of Agriculture and Agronomic Sciences (FASA), University of Dschang. Thus many came to know the definition of Agroforestry and have developed interest in it only during the 1-week sensitization workshop that was organized by RCA Bambili and sponsored by ANAFE, AHT Region in Bambili in April 2005.

These gaps and many other problems are mostly felt at farmer's level. The number of qualified specialists in the area of AF education and other areas have dropped due to the old age and retirement of some teaching staff. There has been no recruitment of extension workers since 1987. These have militated against updating the curriculum of Agricultural Training Institutions in Cameroon.

To improve the quality of specialists and extension workers there is a need to update the curricula of these training institutions and more importantly to develop specific curricula with a focus on the specificity of each agro-ecological zone and its influence on climate change. Thus good agricultural practices feasible and adaptable to each specific agro-ecosystem and beneficial to farmers and their environment are needed. A sound AF extension educational system therefore needs to be elaborated urgently.

Conclusion and Recommendations

Cameroonians should stop thinking that going to school is a guarantee for a government job but use the skills and knowledge they would have acquired to work towards becoming self-reliant. This entails putting in practice some entrepreneurship activities related to Forestry and Agro-Forestry. Agricultural Training Institutions in Cameroon have the duty to ensure that their trainers and trainees are well equipped with knowledge and skills on relevant, effective and dynamic Forestry and Agroforestry practices. This means updating and upgrading their curriculum. Policy makers in Cameroon should also develop interest in the need for sustainable management of natural resources and environment and then stimulate interest in the staff of ATI as a pre-requisite for better Agriculture and Agroforestry Education in the country.

There is an urgent need for reinforcing AF Education in ATI to meet the new opportunities in the extension of AF practices. Most importantly those technologies and systems that have proven their efficiency and sustainability in specific agro-ecological regions should be emphasized and replicated.

ANAFE should advocate for the development of an AF curriculum for all the ATIs in Cameroon to keep them up to date. To achieve this, there is a need for developing a common and appropriate curriculum for ATI of Cameroon that should respond to the concerns of sustainable development and natural resources management. This requires a focus on the following as pre-requisites:

- Research work nationwide to identify the scope for the introduction of AFE
- Design a more relevant and functional curriculum for ATIs in Cameroon.
- Relate such curricula to bio-physical and socio-economic environment of each agro-ecological region.
- More awareness created amongst the stakeholders on the complexity of climate's elements and their vulnerability to change and then include this notion into the curriculum.
- Government to develop policy and measures to mitigate climate change at national level.

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38. Institutionalization Challenges for Climate Change Management

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Abstract

The issues brought about by climate change cut across many disciplines, sectors and institutions. In many countries, there is confusion regarding the responsibility for climate change research, education and policy implementation. Well planned institutionalization of climate change can engender good public understanding of climate change issues. In Sub-Saharan Africa, pressing development priorities such as governance, education and health preoccupy planners and the public. Issues such as the carbon trade are little understood and poorly implemented. Industries need substantial information and training to understand and comply with the regulatory policies, instruments and mechanisms being developed at international, regional and country levels. In recent years we have observed the emergence of a plethora of institutions (mostly private) that deal with climate change mitigation and adaptation projects. However, there is very little coordination, collaboration or synergy. Conveying the right messages is as crucial as carrying out research to understand the processes and effects of climate change, or implementing mitigation or adaptation projects. Universities have a pivotal role to play in educating the academia, the policy makers, and the public and private institutions. In addition climate change has not been integrated in the university curricula. This paper identifies key processes that require appropriate institutionalization of climate change issues at national level. It is suggested that knowledge management, policy, planning and implementation are the cardinal areas of intervention that require mainstreaming.

Key words: climate change, institutionalization, mitigation, adaptation.

Introduction

Article 2 of the 1992 United Nations Framework Convention on Climate Change (UNFCCC) is aimed at stabilising greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The Kyoto Protocol, which was agreed in 1995, recognized the common but differentiated responsibilities of countries and institutions. This is based on the understanding that the polluters and the victims of pollution are highly differentiated. Thus the issue of justice in terms of countries and regions taking proportional responsibilities for their actions is highly sensitive but acknowledged. Besides the social and technical aspects of climate change, indications are that results of any actions taken will take decades, if not centuries to manifest their effects. It is in this complex environment that decisions have to be made and resources committed to implement them. The intricate political and economic balance is hard to achieve without strong appropriate monitoring and lobbying institutions. Box 38.1 captures the essence of controversies involved.

Mitchell and Keilbach (2001) present an interesting matrix of the asymmetric externality of climate change where strong or weak perpetrators and victims are analyzed in terms of outcomes of their actions and the challenges of achieving corrective and fair responsibilities. Essentially, countries can be classified as strong or weak perpetrators of climate change, strong or weak economically and strong or weak politically. Falling in the weak positions (the case of many developing countries) is disastrous, because such a country becomes a victim (recipient of pollution and the effects of climate change without the ability to influence, prevent, mitigate or adapt to the effects.

Koremenos *et al.* (2001) make a case for the design of rational institutions to deal with climate change issues. Many other authors suggest networking mechanisms that allow dialogue and information sharing. Greenhouse gas emissions are closely associated with social and economic development and there are delicate trade-offs in their reduction. Some form of international interceding mechanisms is imperative. Peer pressure is an essential element of a strategy for achieving some change of behaviour and reinforcing mitigation and adaptation measures.

Under the current Kyoto Protocol framework, carbon bio-sequestration mechanisms are not working well for forestry, especially in developing countries. Only one out of 1059 registered Clean Development Mechanism (CDM) projects is a forestry project. Approved approaches, especially afforestation and reforestation (A/R), are not functional because they are cumbersome (excessively regulated and bureaucratic). There is a serious shortage of human and institutional expertise in the developing world to enable them access carbon markets. Poor communities, despite being the most exposed to the effects of climate change, are least able to access carbon funds. Yet the CDM was meant to enhance bio-sequestration and simultaneously promote sustainable development in developing countries. Conversely, the Joint Implementation scheme and other intra-European and industrialized country carbon bio-sequestration schemes have been growing rapidly. A high level of expertise is required to develop and register a project, and this expertise is beyond the reach of communities and organizations in most developing countries.

In Africa, most carbon projects are nascent and facing challenges related to land tenure, management and market access. There is a need for new approaches to smallholder carbon management that would directly benefit poor people in poor countries. This cannot succeed without effective institutions.

Global institutions and mechanisms

The Kyoto Protocol (1997) defined 3 mechanisms for developed countries (listed in annex 1 of UNFCCC) to reduce the GHG emissions attributable to them through non-domestic sources. The mechanisms are a) Carbon trading, b) Joint implementation (JI) and c) Clean Development mechanism (CDM). There are major challenges regarding the implementation of these mechanisms, instruments for control as well and legal and ethical aspects. Many institutions are involved and sometimes it is not clear what institutions provide guidance at the different levels (national to global). Cardinal functions of national level Climate Change organizations include: Knowledge Management (Research, Education, Collating, Synthesizing, Sharing, lessons); Policy and International Dialogue; National Planning and Financing; Local level implementation (Figure 38.1). Table 38.1 lists gives an overview of International Institutions and Processes.

Box 38.1

Greenhouse gas concentrations before the industrial revolution (around 1850) were about 280 parts per million (ppm). Current concentrations are around 380 ppm. It is uncertain exactly what concentration would prevent dangerous climate change, as climate sensitivities (i.e. how the climate exactly responds to a shifted radiative balance) are not known exactly. However, working with a range of likely climate sensitivities derived from paleoclimatic data, it has been argued that an increase in global mean temperature of 2°C would not lead to extreme climate risks or very costly impacts. Early models indicate that a concentration of 550 ppm (or double the pre-industrial level) would be low enough to stay below the 2°C (IPCC, 2001), but others have argued that the risk of "overshooting" that temperature increase is around 80% at a stabilisation level of 550 ppm, and argue that stabilisation at 450 ppm or even lower would be necessary (Meinshausen and Hare, 2005). The emission reductions associated with those stabilisation levels are achievable with current technologies, but will have profound impacts on the way energy is used and produced.

Source: Heleen de Coninck - May 2007: Amsterdam Conference on Human Dimensions of Global Environmental Change

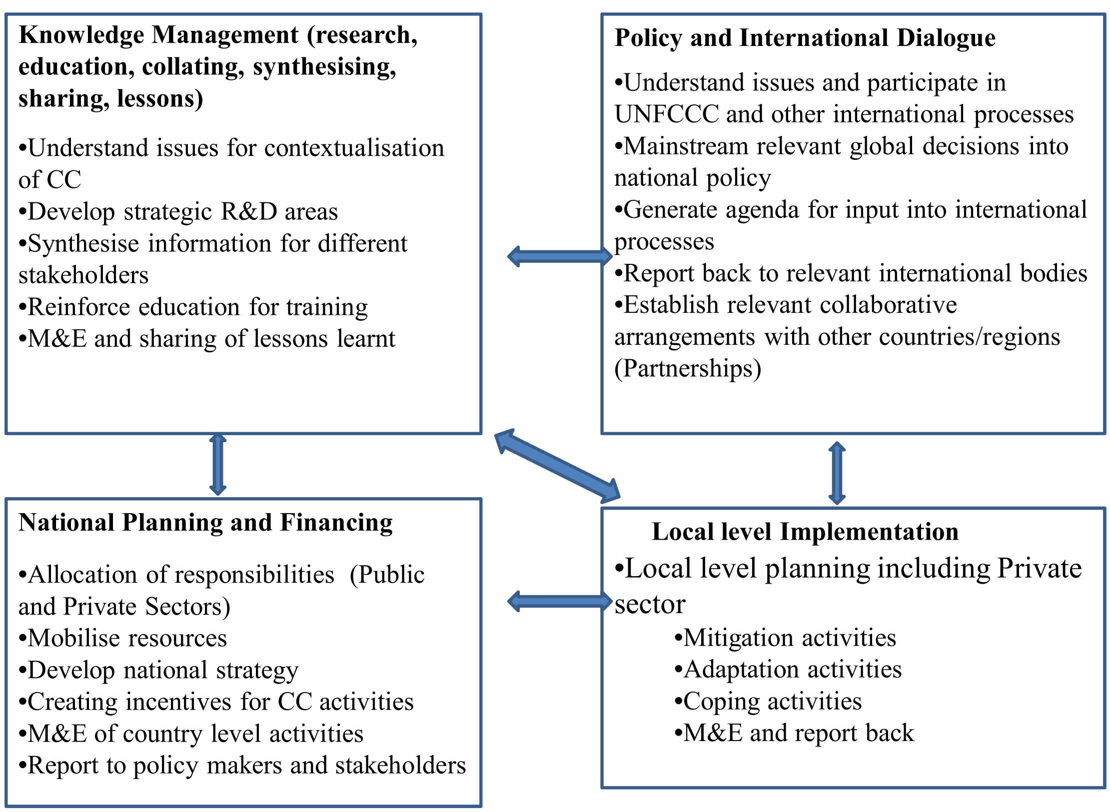

Figure 38.1. Framework for climate change institutionalization in sub-Saharan Africa

Table 38.1. International Institutions and Processes

Convention	Functions
IPCC, Intergovernmental panel on climate change	Puts together data concerning climate change and guides UN actions and negotiation processes.
UNFCCC, United Nations Framework Convention on Climate Change (1992)	The UNFCCC provides a framework for policy to deal with climate change.
Kyoto Protocol (1997)	Highlights adoption of climate change convention and specific commitments developed by individual countries. It deals with reduction of greenhouse gas emissions from developed countries through non-domestic sources. Development of mechanisms for carbon trading and joint implementation activities. Also highlights adoption of climate change conventions and specific commitments by countries.
COP, Conference of Parties	Convenes meetings of stakeholders with interest to implement mitigation and adaptation activities. It has run COP 1 up to 11 until now. It is interested in institution structures and financial mechanisms including social networks and access to resources. Has particular interest on climate change impact on the rural poor, particularly looking at ways of reducing environmental risk, strengthening of livelihood activities and minimizing stress to social institutions.
CDM, Clean Development Mechanism	This was created by the Kyoto Protocol as the formal channel for supporting low-carbon investment in developing countries. It allows for both governments and private sector to invest in projects that reduce emissions in fast-growing emerging economies and provides one way to support links between different regional emission trading schemes.

Table 38.2. Interrelationships of climate change across different economic sectors

Sector	How it is influenced by climate change	How it Influences Climate Change
Environment	Impacted by extreme events such as droughts and floods.	Environmental improvement programmes can be designed to reduce greenhouse gas emissions and improve carbon sequestration.
Water and Fisheries	Water quality and availability is affected. Loss of the niches for growing fish and loss of production.	
Energy	Extreme events influence the availability and quality of water for hydroelectric power generation.	Energy utilization and conservation strategies would reduce e.g. Use of fossil fuels increase the level of greenhouse gases in the atmosphere; Use of clean energy

Agriculture and Forestry	Reduced predictability of weather conditions for crop, livestock and forestry production.	Good agronomic/ livestock feeding practices combined with good selection of breeds and tree species would cut down on greenhouse gas emissions and improved carbon sequestration. Avoided deforestation.
Health	Extreme events can increase the prevalence of certain diseases e.g. malaria and waterborne disease. Reduced agricultural production can also lead to malnutrition.	
Education	Extreme events e.g. floods, can lead to disruptions of learning.	Education increases awareness and appreciation of climate change problems and actions.
Trade, Commerce and Industry	Erratic production is a threat to sustainability of production. A new commodity, Carbon has entered the market.	Trade in forest products can accelerate forest degradation and thereby climate change.
Planning	Disruption of plans; Increased emergencies, risks and uncertainties.	Good plans integrating reduction of greenhouse gases would positively impact on climate change
Disaster Management	Overload of capacity to react to disasters.	

There are major challenges on how to interpret and implement globally agreed conventions at the national and local scale. These include:

- Information availability to all stakeholders
- Funding mechanism for climate change activities
- Division of roles
- Ethical issues in relation to the business generated by climate change
- Communication challenges

Like HIV/AIDS, climate change issues influence and are influenced by very many sectors. These are organized differently across countries. The major sectors influenced include those listed in Table 38.2.

Given the interactions of the various sectors with climate change, a framework for climate change institutionalization in sub-Saharan Africa is presented in Figure 38.1. It gives components of knowledge management (research, education, collating, synthesizing, sharing lessons); Policy and International Dialogue; National Level Planning and Financing and Local level implementation.

Conclusions

The challenges posed by climate change cut across many disciplines, sectors and institutions. Sub-Saharan Africa needs to institute well-planned institutionalization of climate change issues to ensure that the countries benefit from international processes; contribute to research and development; allocate resources for implementation of agreed upon activities at national level and be able to advise the communities affected by climate change on appropriate adaptation and mitigation strategies. Coordination, collaboration and synergy at all levels is required to cope with the adverse effects of climate change.

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39. Information Training and Outreach Centre for Africa – ITOCA

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Abstract

The Information Training and Outreach Centre for Africa (ITOCA) is a capacity building organization aimed at enhancing information and communications technology (ICT) skills for African librarians, information specialists, scientists, researchers and students in sub-Saharan Africa. ITOCA was established in 1999. Currently ITOCA runs the promotion, training and support of four major programmes in SSA: The Essential Electronic Agricultural Library (TEEAL), Access to Global Online Research in Agriculture (AGORA), Health Internetwork Access to Research Initiative (HINARI) and Online Access to Research in the Environment (OARE). ITOCA has trained over 1,200 information professionals, scientists and students in electronic information programmes in about 30 train-the-trainer short courses run in over 30 SSA countries in the last 10 years. Participants have valued the information provided by the four programmes. Information related to climate change is readily available from the four programmes and these can be used to source information pertaining to climate change integration into agricultural education.

Key words: ITOCA, TEEAL, AGORA, HINARI, OARE, sub-Saharan Africa

Introduction

The Information Training and Outreach Centre for Africa (ITOCA) www.itoca.org is a not-for-profit capacity building organization aimed at enhancing information and communications technology (ICT) skills for African librarians, information specialists, scientists, researchers and students in Sub-Sahara Africa. Formerly, The Essential, Electronic Agricultural Library (TEEAL) Africa Office, ITOCA was established in February 1999 as a marketing and support office for Cornell University's Albert R. Mann Library TEEAL www.teeal.org programme for Africa. Currently, the organization runs the promotion, training and support of four major programmes in sub-Sahara Africa: TEEAL, AGORA, HINARI and OARE which are funded through grants from Cornell University, FAO, WHO, and CTA of Netherlands and the Rockefeller Foundation.

ITOCA was registered in South Africa in 2006 under Section 21 as a Public Benefit Organization (PBO). It is aimed at promoting and building capacity for scientists, researchers and information professionals on the use of ICTs in development work in the region. Its main thrust is providing the research and academic communities with access to up-to-date affordable access to published scientific scholarly literature and developing required relevant skills. This is achieved through:

- Undertaking outreach and training programmes in ICTs and related activities

- Holding institutional, national and regional training workshops, seminars and capacity building programmes
- Providing technical support and specialized consultancy for ICT programmes
- Implementing information research projects
- Conducting M and E for ICT projects

ITOCA provides skills aimed at *bridging the digital divide* between the developed and developing countries in the fields of health, agriculture, the environment and related disciplines.

Activities

ITOCA has trained over 1,200 information professionals, scientists and students in electronic information programmes in about 30 train-the-trainer short-courses run in over 30 Sub-Saharan African countries in the last ten years. Since April 2005, ITOCA has conducted 3-4 day Information Literacy workshop courses focusing on the access and use of the AGORA-Access to Global Online Research in Agriculture; HINARI-Health Internetwork Access to Research Initiative; OARE-Online Access to Research in the Environment and TEEAL – The Essential Electronic Agricultural Library in Angola, Botswana, Cameroon, Congo, Democratic Republic of Congo, Ethiopia, Kenya, Lesotho, Malawi, Mali, Mozambique, Nigeria, Rwanda, Senegal, South Africa, Tanzania, Togo, Sierra Leone, Mozambique, Uganda, Zambia, and Zimbabwe. These capacity building programmes are funded through grants and contracts from The Rockefeller Foundation, Cornell University-TEEAL, FAO, CTA, and WHO and hosted by collaborating local universities and National Research Institutions in the targeted countries.

HINARI, AGORA and TEEAL Programmes

AGORA, HINARI and OARE are three major Internet-based portals that provide low-income countries throughout the world, though primarily Africa, free or low cost access to the world's journal literature in agriculture, health and the environment. This means for the first time in history, researchers in eligible countries can have access to the same kind of information as their peers in more economically advanced countries and participate in the global research agenda. AGORA, HINARI and OARE represent an important public-private partnership involving commercial and academic publishers, universities, and United Nations agencies. Though they operate independently, AGORA, HINARI and OARE were modeled on HINARI and they have strong collaborative ties.

HINARI

www.who.int/hinari

HINARI - Access to Research Initiative gateway, launched in 2002 and led by the World Health Organization, is an online gateway of the latest and best information in public health, biomedicine and related social sciences. There are over 5,000 scientific publications by 100+ publishers (including most of the major scientific presses) in one of the world's largest collections of biomedical literature. Almost 2,600 institutions in 113 countries are registered, making it possible for thousands of physicians and researchers in universities, medical schools, research institutions, teaching hospitals, and government offices to have access to up-to-date biomedical and public health information. In the 42 African countries that are eligible, over 800 institutions have registered for HINARI. HINARI has been described by the WHO Director-General Dr Gro Harlem Brundtland as "perhaps the biggest step ever taken towards reducing the health information gap between rich and poor countries."

AGORA

www.aginternetwork.org

Access to Global Online Research in Agriculture (AGORA) is an initiative led by Food and Agriculture Organization (FAO) to provide free or low-cost access to major scientific journals in agriculture and related biological, environmental and social sciences to public and qualifying not-for-profit organizations in developing countries. Launched in October 2003, AGORA is a unique collaboration of public and private partners including the World Health Organization (WHO), major scientific publishers, Cornell University's Mann Library, the Rockefeller Foundation, the UK's Department of International Development (DFID), CABI publishing and others. Through its Internet gateway www.aginternetwork.org, AGORA provides access to over 1200 journals from the world's leading academic publishers.

AGORA’s collection focuses on food, agriculture, environmental science and related social sciences. Since its launch, About 1000 institutions in 107 countries have registered. Almost all national agricultural research organizations in Africa have registered. Of the 69 countries that are eligible for AGORA’s free journal access, over half are in sub-Saharan Africa.

OARE

www.oaresciences.org

Online Access to Research in the Environment (OARE), an international public-private consortium coordinated by the United Nations Environment Programme (UNEP), Yale University, and leading science and technology publishers, enables developing countries to gain free access to one of the world's largest collections of environmental science literature. There are currently 1817 scientific journal titles in OARE owned and published by over 300 prestigious publishing houses, scholarly societies, and scientific associations are now available in 107 low income countries. Research is provided in a wide range of disciplines, including biotechnology, botany, climate change, ecology, energy, environmental chemistry, environmental economics, environmental engineering and planning, environmental law and policy, environmental toxicology and pollution, geography, geology, hydrology, meteorology, oceanography, urban planning, zoology, and many others.

TEEAL

www.teeal.org

TEEAL is a project of Cornell University's Albert R. Mann Library in cooperation with over 60 major scientific publishers, societies and index providers. Over the years, critical financial support has been provided by the Rockefeller Foundation. The TEEAL Project is administered through Mann Library's Collection and Services Department, where a small staff oversee production, distribution, outreach and training and ITOCA conducts awareness and training missions all over the continent

Tertiary Agricultural Education Portal for Africa

www.aet-africa.org

ITOCA runs the Tertiary Agricultural Education (TAE) portal www.aet-africa.org funded through a grant by the Bill and Melinda Gates Foundation. The TAE portal tracks and highlights human capital development data in tertiary agricultural education in Africa. Over 400 universities, colleges, polytechnics and training institutes participate in the programme.

The HIN-AG-OA User Africa Community

The Africa User Community development programme for HINARI, AGORA and OARE users launched in 2007 and funded by the Tropical Diseases Research Programme of WHO is facilitated and moderated by ITOCA. With an extensive network of over 400 professors, librarians, researchers from across the continent, the network forum discusses and shares experiences on varied information literacy issues and the use of e-resources in learning, teaching and research.

Conclusion

ITOCA's product base of TEEAL, HINARI, AGORA and OARE are serving as useful sources of information for practitioners working in the area of agriculture and environment in SSA. Participants to the training in the use of these programmes have valued the information obtained from these sources. Information for integration of climate change into tertiary agricultural education curricula can easily be obtained using these sources

40. About ANAFE

Launched in April 1993, ANAFE is one of the largest working African networks of educational institutions. Currently ANAFE membership comprises 132 universities and colleges in 35 African countries. ANAFE is hosted at the headquarters of the World Agroforestry Centre (ICRAF) in Nairobi, Kenya. The initial objective of ANAFE was to incorporate Agroforestry and multi-disciplinary approaches into agricultural education. Over the years, ANAFE's mandate has expanded to include agriculture and natural resources education. ANAFE's mission is "To improve Agricultural education for impact on development". This mission is achieved through a wide range of activities including policy advocacy; facilitating knowledge sharing; promoting women and youth in agriculture; HIV/AIDS mitigation; mitigation and adaptation of climate change; review of curricula and development of learning resources. ANAFE works through four regional chapters known as RAFTs (Regional Agricultural Fora for Training)—one each in Eastern and Central Africa (ECA), Southern Africa (SA), Sahelian countries (Sahel) and the Africa Humid Tropics (AHT). ANAFE has national chapters NAFTs (National Agricultural Fora for Training) in 21 countries.

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42. Selected Conference Photos

Sessions in progress at the conference

Sessions in progress

Poster Session

Keynote presenters: Dr. A. Saka

Keynote presenters: Prof. E. Van Zyl

Keynote presenters: Jan Beniest

Keynote presenters: Per Rudebjer

Participants interacting

Conference Breaks

Secretariat at work


ANAFE Board Elections: The newly elected continental Board Chair, Prof. J. Saka takes charge of business.


The Newly-elected Continental Vice Board Chair, Dr. M.L. Avana Tientcheu takes her position

The Executive Secretary, Board and Vice Chairs

Board Chair, Prof. Saka giving closing remarks