ENVIRONMENTAL SUITABILITY
AND AGRO-ENVIRONMENTAL ZONING
OF KENYA FOR BIOFUEL PRODUCTION

PREPARED BY
Benard O. Muok (African Centre for Technology Studies), Meshack Nyabenge
(World Agroforestry Centre, ICRAF), Benson Okita Ouma (Kenya Wildlife
Service), Anthony O. Esilaba and Tabeel Nandokha (Kenya Agricultural Research
Institute) and Benard Owuor (Kenya Forestry Research Institute)

CONTRIBUTORS
Shadrack Kirui, Victor Onyango, Ayub Shaka, Charles Situma and Caroline Sinei

©JUNE 2010

Design & Production: Eyedentity Ltd.
ACKNOWLEDGMENT
This study was lead by the African Centre for Technology Studies (ACTS) through Policy Innovation Systems for Clean Energy Security (PISCES). Policy Innovation Systems for Clean Energy Security (PISCES) is a five-year Research Programme Consortium funded by the UK’s Department for International Development (DfID) to develop new knowledge for the sustainable use of bioenergy to improve energy access and livelihoods in poor communities. ACTS’ Executive Director and PISCES Research Director is Prof. Judi Wakhungu. PISCES Project Manager is Dr. Benard Muok.

The study was funded by the United Nations Environmental Programme (UNEP) through its Bioenergy Policy and Planning Support Facility. The facility was established to provide ad hoc support to governments on issues related to development and implementation of sustainable bioenergy policies, strategies and measures. We thank Martina Otto for the great support provided. We wish to thank all the heads of the institutions whose experts participated in the study. The authors would like to give special appreciation to Sue Canney (DEGJSP/Pipal) for providing valuable information on jatropha and proof reading the draft, Peter Roberts (DfID) and Colin Pritchard (University of Edinburgh) for valuable comments. To all the farmers whom we visited in the villages, who provided important information which helped to make this report what it is, we say ‘Thank you very much’.

Although PISCES research is funded by DfID, the views expressed in this report are entirely those of the authors and do not necessarily represent DfID’s own policies or views. Any discussion on this content should therefore be addressed to the authors and not to DfID.

Disclaimer
The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the United Nations Environment Programme concerning the legal status of any country, territory, city or area or its frontiers or boundaries. Moreover, the views expressed do not necessarily represent the decision or the stated policy on the United Nations Environment Programme, nor does citing of trade names or commercial processes constitute endorsement.
The objective of this study was to conduct an agro-climatic and environmental zoning of Kenya in order to produce maps showing the country’s biodiversity, variety of land uses, protected areas and sites that were suitable for growing biofuel feedstock. A specific goal was to attempt to determine the amount of land in terms of acreage that can be devoted to a particular feedstock. The study will be useful in planning and projecting Kenya’s potential for sustainable bioenergy production, and in serving as a background document for the Draft National Biofuel Policy, and the broader community of biofuel stakeholders.

A guiding principle of the study was that the use of biomass for fuel and energy purposes does not necessarily jeopardize Kenya’s ability to ensure food security, nor should it endanger Kenya’s goal of achieving environmental priorities such as protecting forests and wildlife, preventing soil degradation and safeguarding water resources.

The study took place between January and April 2010 when the United Nations Environment Programme (UNEP) accepted to fund a proposal presented by the African Centre for Technology Studies (ACTS) and the Ministry of Energy (MoE). The study was carried out by a wide range of experts from various government ministries, research institutions, and international organizations. The experts were drawn from ACTS (lead organization and overall coordinator), World Agroforestry Centre (ICRAF), Kenya Agricultural Research Institute (KARI), Kenya Forestry Research Institute (KEFRI), Kenya Wildlife Service (KWS), Department of Resource Surveys and Remote Sensing (DRSRS), Department of Metrology, Ministry of Health (MoH) and Kenyatta University.

The outputs of the study include:

i) Compilation of biofuel feedstock growing conditions,

ii) Maps showing
   a) Feedstock suitability sites
   b) Sites available for feedstock cultivation

iii) Area of land available for each feedstock and

iv) Recommendations

We are deeply indebted to UNEP for funding this important national exercise. Successful completion of this study was possible because of the dedicated work and enthusiasm of the team of experts and their respective organizations. I would also like to acknowledge the Policy Innovation Systems for Clean Energy Security (PISCES) partners, and the Department for International Development (DfID) representative for reviewing the study. Finally, I am deeply indebted to my colleagues at ACTS for their leadership and coordination of this exercise from inception to completion. The experts remain responsible for the views documented here, and for any omissions and errors.

Signed,
Prof. Judi W. Wakhungu
EXECUTIVE SUMMARY

When produced in a sustainable and equitable manner, biofuels can increase Kenya’s energy self-sufficiency, support rural development as well as reduce deforestation and GHG emissions compared to fossil fuels. The output of this study is intended to assist the national authorities of Kenya in better planning of the land use and assessment of the land resources and feedstocks suitable for production of biofuels (first generation). The study was funded by United Nations Environment Programme (UNEP)’s Bioenergy Policy and Planning Support Facility and lead by African Centre for Technology Studies (ACTS). The main contributors to this study were experts drawn from World Agroforestry Centre (ICRAF), Kenya Agricultural Research Institute (KARI), Kenya Forestry Research Institute (KEFRI), Kenya Wildlife Service (KWS), Department of Resource Surveys and Remote Sensing (DRSR) and Kenya Meteorological Department (KMD).

The study aimed at determining suitability areas of twelve biofuel feedstocks in Kenya and to identify high value biodiversity areas as well as areas of high socio-cultural values to be recommended for exclusion in biofuel production. This underpins the Draft National Biofuels Policy that has been developed through a multiple stakeholder process from November 2008. The overarching goal of the study is to ensure that, when properly implemented, biofuel development will be economically productive alongside equitable land use, environmental preservation and reliable food production. Feedstocks covered in this study are sugar cane, sweet sorghum, cassava, *Jatropha curcas*, *Croton megalocarpus*, castor, cotton, sunflower, canola (rapeseed), coconut, oil palm and *Crambe abyssinica*.

SPECIFIC OBJECTIVES

The study aimed at fulfilling the following specific objectives:

i. Develop protocols for agro-climatic and environmental zoning for biofuel production in Africa.

ii. Delineate nationally and internationally recognized and non-recognized biodiversity conservation areas including important bird areas.

iii. Delineate important wetlands, water catchment areas and slopes of more than 45%.

iv. Identify and delineate mapped important wildlife corridors.

v. Identify and map main land uses (crop lands, pastoral areas and wildlife movement paths [3km width]).

vi. Develop feedstock suitability maps based on the biotic and edaphic factors.

Main Guidelines

Data collection and zoning will follow the following guidelines:

i. Exclude sensitive areas from large-scale biofuel cultivation, such as: biodiversity conservation areas, protected areas, forests, river basins and wetlands, Wildlife movement paths (3km width)

ii. Avoid competition with food production;

iii. Indicate areas with agricultural potential for uncontroversial and successful production of biofuel crops or feedstocks.

The overall method entailed the following activities:

i. Data collection and compilation

ii. Data processing to produce suitability areas

iii. Calibration of suitability map with field data

iv. Integration of suitability layers with socio-economic data

The objective is to establish the location and quantity of land areas that would be available for each biofuel crop investment in Kenya, using key management and conservation variables such as:

i. Areas outside gazetted establishments (forest, parks, and game reserves),

ii. Areas within and outside food and cash crops farming, and
iii. Within arable and non arable land.
iv. Important bird areas
v. Slopes more than 45%
vi. Wetlands and areas of high biodiversity value for conservation outside the protected areas,
vii. Natural animal corridors (animal movement areas 3km width)
viii. Human-wildlife conflict areas

By conversion of each management and conservation variable into raster and Boolean standardized format, and overlaying them with biophysical-based suitability layers, a series of suitability maps for each feedstock within different zones were produced. Areas were derived by multiplying value counts in each raster by pixel area.

The study has shown that coast, central and western Kenya have the highest potential for feedstock production given the high number of feedstocks suitability per scene. Northern and south western Kenya has the lowest potential. The study demonstrated that suitable areas for production of most feedstocks lie within arable land areas whether the land is cultivated or uncultivated. Sweet sorghum and castor are the only feedstock which showed high suitability in agriculturally marginal to moderate zones. These findings call for a careful balance in the choice of feedstock and selection of the site of feedstock production in order not to compromise food security. There are several options that could be considered such as planting along boundaries: such is the case of Jatropha in some countries such as India. The feedstock can also be intercropped with food crops where the two are compatible. Whatever the case, care must be taken to ensure that food production is not compromised, bearing in mind that farmers are rational decision makers who are able to make decisions based on the opportunity cost provided by biofuel feedstocks. For edible biofuel feedstocks such as sweet sorghum, cassava, sunflower, etc which farmers are already growing on their own for food purposes, the scenario presented could be different depending on how production is planned. For example, it has been repeatedly claimed that planting sweet sorghum will enhance food security.

In terms of the size of suitable area, sweet sorghum has the highest coverage of 263,965 km² (46.4%) followed by castor at 240,494 km² (42.2%) and Jatropha at 221,937 km² (39%). The feedstock with the least area suitability is coconut with 4,489 km² (0.3%) followed by oil palm at 12,204 km² (2.1%) and canola at 23,763 km² (4.2%). Feedstocks with wider suitability could be more appropriate when considering a national biofuel programme, but this is not to say that the smaller feedstocks in terms of area should be ignored, since different feedstock have their advantages and disadvantages. It can also be expected that indigenous feedstocks such as Croton megalocarpus may emerge to have a more extended range than predicted and be less problematic than currently better known crops such as Jatropha.

The country has some unique and important biodiversity endowments, most of which are under threat. While some of the protected areas are well understood and protected under the relevant legislation, important biodiversity conservation areas outside the projected areas do not have equal protection under the law. There has been little or no economic assessment of the local, national and global environmental values of the areas of high biodiversity areas outside protected areas. With accelerated expansion of agriculture and introduction of biofuels, assessment and conservation of these areas need to be evaluated quickly as a national priority.

RECOMMENDATIONS

1. As has been noted in the preceding discussion, almost all the feedstocks have best yield in agriculturally high potential arable lands. Only few feedstocks such as castor and sweet sorghum were classified as highly suitable in agriculturally marginal to medium potential areas. Others such as Jatropha are tolerant to drought and therefore, once established, can survive in agriculturally marginal areas. However, without sufficient rainfall and nutrients, general yield and productivity is very low, making these areas unprofitable for investing in non-irrigated feedstock production. Therefore, careful balancing needs to
be done between high suitability areas for feedstock production and the overarching need to safeguard food production and water resources.

2. Marginal and degraded areas, where biofuels pose the least competition with food crops may not yield commercial results with most feedstocks unless accompanied by heavy investment in soil fertility improvement, water harvesting and conservation. Research is also needed to develop arid, semi-arid feedstock varieties that are productive in such areas. There is a need for clear policies, including appropriate policy incentives to attract investors to the agriculturally marginal (degraded) areas.

3. All biofuel feedstocks in Kenya can directly benefit from research and improvement programmes. Issues of potential land use change, high water usage and water and air pollution will remain, but these can be addressed through adhering to careful agro-ecological zoning for biofuel production.

4. In view of increased demand for extensive land areas for investing in biofuels, there is need to improve the land administration systems to deal with conflicting claims between different vested interests and the traditional land usages and ownership rights that are emerging under biofuels expansion. There is need to ensure that changes and production practices associated with biofuel production are sustainable. Responsible land allocation, land use change and policy enforcement, will minimize competition over land, and therefore food insecurity and encroachment on protected and communal areas.

5. Whether or not to promote crop based feedstock and/or feedstocks that also yield edible oils, is a point that needs to be carefully addressed. Though not based on any policy guidelines, in Kenya, jatropha, castor and croton have received high priority among development agents, while edible oils such as palm oil, coconut, sunflower, crambe and canola have so far been less considered. This is in contrast to Tanzania, where large scale planting of palm oil for biofuel has been going on. There is a need for a clear policy on this to guide investors on suitable Kenyan feedstock development.

6. A strategic, comprehensive and credible Environmental Impact Assessment (EIA) that prevents unsuitable production, needs to be undertaken for all biofuel development projects especially those in areas of high biodiversity, wildlife, forest and water conservation. The EIAs conducted must meet international standards such the internationally recognized principles published by IAIA. The CBD and Ramsar Conventions as well as the Round table on Sustainable biofuels (RSB) and UNEP have all produced guidance on EIAs and these, along with the current NEMA guidelines can provide for environmental and social safeguards in biofuel development.

7. Listed and identified areas of high conservation value, global and national endemic species habitats, biodiversity hotspots, remaining woodland and forest stands, wetlands and key water catchment areas need to be actively excluded for any large scale biofuel expansion. Expansion in such areas needs to be banned, as without these, Kenya’s functioning but fragile ecosystems will not support future development.

8. A development and conservation Master Plan should precede any large scale biofuel development to ensure that social, economic, conservation and development objectives are all taken on board on the same level and scale. Lost biodiversity and endemic habitats which have evolved over decades and centuries are irreplaceable. It is critical that conservation planning precedes development planning, to avoid irreversible biodiversity and habitat losses. It is also important to develop management plans and mobilize resources to support any conservation areas set aside, in order to maintain globally threatened species, fragile ecosystems and associated invaluable ecological goods and services. Well-managed conservation areas would in turn provide a healthy environment and safe buffer zones for any future development projects and provide adequate insect pollinators, birdlife and natural pest predators.

9. Since most of the biodiversity resources are of trans-boundary in nature, the study recommends carrying out a similar study in all eastern Africa countries.
# TABLE OF CONTENTS

Executive Summary ................................................. v
Table of Contents .................................................. ix
List of Acronyms ................................................... x
List of Tables ....................................................... xi
List of Figures ....................................................... xii
1.0 Background and Introduction ................................ 1
1.1 Background .................................................... 1
1.2 Introduction ................................................... 1
1.2.1 Opportunities and Risks .................................... 2
1.2.3 Sustainable Biofuels ........................................ 5
1.3 History of Suitability Mapping in Kenya ................. 5
1.4 Objective of the Study ........................................ 6
2.0 Methodology .................................................... 7
2.1 Data Collection and Compilation ............................ 7
2.2 Data Processing to Produce Suitability Areas .......... 7
2.3 Calibration of Suitability Map with Field Data .......... 7
2.4 Integration of Suitability Layers with Socio-economic Data 8
3.0 Results .......................................................... 11
3.1 Biofuel Suitability per Region ............................... 11
3.2 Bioethanol Feedstocks Types and Zoning ............... 12
3.2.1 Sugarcane .................................................. 12
3.2.2 Sweet Sorghum ........................................... 12
3.2.3 Cassava ..................................................... 18
3.2.3 Biodiesel Feedstocks Types and Zoning ............ 29
3.3.1 Jatropha curcas ........................................... 29
3.3.2 Croton megalocarpus ..................................... 35
3.3.3 Canola (Rapeseed) ......................................... 40
3.3.4 Castor ...................................................... 44
3.3.5 Cotton ...................................................... 50
3.3.6 Sunflower .................................................. 55
3.3.7 Coconut palm .............................................. 59
3.3.8 Palm Oil .................................................... 63
3.3.9 Crambe ..................................................... 68
4.0 Discussion ........................................................ 73
5.0 Recommendations and Conclusion ....................... 77
6.0 References ....................................................... 79
7.0 APPENDIX 1 ..................................................... 81
7.1 National Parks, Reserves, Wildlife Dispersal Areas and Conflict Areas 81
7.2 Wetlands of Kenya ............................................ 81
7.3 Biodiversity Conservation .................................... 83
7.4 Forests of High Biodiversity Value that lie outside Protected Areas 83
8.0 Appendix 2 Suitability Maps ................................ 89
**LIST OF ACRONYMS**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACTS</td>
<td>African Centre for Technology Studies</td>
</tr>
<tr>
<td>AEZ</td>
<td>Agro-Ecological Zoning</td>
</tr>
<tr>
<td>CBD</td>
<td>Convention on Biological Diversity</td>
</tr>
<tr>
<td>CITES</td>
<td>Convention on International Trade in Endangered Species</td>
</tr>
<tr>
<td>CO2</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>DfID</td>
<td>Department for International Development</td>
</tr>
<tr>
<td>DRSRS</td>
<td>Department for Resource Survey and Remote Sensing</td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental impact assessment</td>
</tr>
<tr>
<td>EJ</td>
<td>Exajoule</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organisation</td>
</tr>
<tr>
<td>GHG</td>
<td>Green House Gas</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographical Information System</td>
</tr>
<tr>
<td>GoK</td>
<td>Government of Kenya</td>
</tr>
<tr>
<td>GTZ</td>
<td>German Agency for Technical Cooperation</td>
</tr>
<tr>
<td>IAIA</td>
<td>International Association for Impact Assessment</td>
</tr>
<tr>
<td>IBAs</td>
<td>Important Bird Areas</td>
</tr>
<tr>
<td>ICRAF</td>
<td>World Agroforestry Centre</td>
</tr>
<tr>
<td>ICRISAT</td>
<td>International Crops Research Institute for the Semi-Arid Tropics</td>
</tr>
<tr>
<td>IUCN</td>
<td>World Conservation Centre</td>
</tr>
<tr>
<td>KARI</td>
<td>Kenya Agricultural Research Institute</td>
</tr>
<tr>
<td>KBA</td>
<td>Key Biodiversity Areas</td>
</tr>
<tr>
<td>KENFAP</td>
<td>Kenya National Federation of Agricultural Producers</td>
</tr>
<tr>
<td>KWS</td>
<td>Kenya Wildlife Service</td>
</tr>
<tr>
<td>MoH</td>
<td>Ministry of Health</td>
</tr>
<tr>
<td>NEMA</td>
<td>National Environment Management Authority</td>
</tr>
<tr>
<td>NP</td>
<td>National Park</td>
</tr>
<tr>
<td>NR</td>
<td>National Reserve</td>
</tr>
<tr>
<td>PISCES</td>
<td>Policy Innovation Systems for Clean Energy Security</td>
</tr>
<tr>
<td>RSB</td>
<td>Roundtable on Sustainable Biofuels</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environmental Programme</td>
</tr>
<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
</tr>
<tr>
<td>WBA</td>
<td>World Biofuel Association</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 1 Suitability levels of jatropha, sugarcane, castor, croton and sweet sorghum .............................. 8
Table 2 Sugar production, consumption imports and exports, 2001-2008 (Mt) ........................................ 13
Table 3 Sugarcane suitability .................................................................................................................. 14
Table 4 Sorghum production, 2003-2008 .............................................................................................. 19
Table 5 Sweet sorghum suitability ......................................................................................................... 20
Table 6 Cassava production, 2003-2007 ............................................................................................... 25
Table 7 Cassava suitability .................................................................................................................... 26
Table 8 Jatropha suitability .................................................................................................................... 31
Table 9 Croton suitability ....................................................................................................................... 36
Table 10 Canola suitability ..................................................................................................................... 41
Table 11 Castor suitability ...................................................................................................................... 46
Table 12 Cotton production by province 2001-2003; 2006 ................................................................ 51
Table 13 Cotton suitability ..................................................................................................................... 52
Table 14 Sunflower suitability ............................................................................................................... 56
Table 15 Coconut production in Kenya, 2003-2007 ............................................................................. 60
Table 16 Coconut suitability .................................................................................................................. 60
Table 17 Palm oil Imports to Kenya for 2007 ....................................................................................... 64
Table 18 Palm Oil suitability ................................................................................................................... 65
Table 19 Crambe suitability ................................................................................................................... 70
LIST OF FIGURES

Figure 1  Number of biofuel feedstocks suitable per scene  11
Figure 2  Sugarcane stalk and cut sugar cane  13
Figure 3  General suitability map of sugarcane  15
Figure 4  Sugarcane suitability map with overall zonation  16
Figure 5  Sugarcane suitability levels with overall zonation  17
Figure 6  Sweet sorghum  19
Figure 7  General suitability of sweet sorghum  21
Figure 8  Sweet sorghum suitability with overall zonation  22
Figure 9  Suitability levels of sweet sorghum  23
Figure 10  Cassava plants  25
Figure 11  General suitability map of cassava  27
Figure 12  Cassava suitability map with overall zonation  28
Figure 13  Jatropha curcas plantation  31
Figure 14  General suitability map of Jatropha  32
Figure 15  Jatropha suitability map with overall zonation  33
Figure 16  Jatropha suitability levels  34
Figure 17  Croton tree, seed and biodiesel  36
Figure 18  General suitability map of croton  37
Figure 19  Suitability map of croton with overall zonation  38
Figure 20  Suitability levels of croton  39
Figure 21  Canola flowers  40
Figure 22  General suitability of canola  42
Figure 23  Suitability of canola with overall zonation  43
Figure 24  Castor tree  45
Figure 25  General suitability map of castor  47
Figure 26  Castor suitability map with overall zonation  48
Figure 27  Suitability levels of castor  49
Figure 28  Cotton plant  52
Figure 29  General suitability map of cotton  53
Figure 30  Suitability map of cotton with overall zonation  54
Figure 31  Sunflower plant  56
Figure 32  General suitability map of sunflower  57
Figure 33  Suitability map of sunflower with overall zonation  58
Figure 34  Coconut tree  60
Figure 35  General suitability map of coconut  61
Figure 36  Suitability map of coconut with overall zonation  62
Figure 37  Oil palm imports to Kenya (1998 – 2007)  64
Figure 38  Palm oil tree  65
Figure 39  General suitability map of palm oil  66
Figure 40  Suitability of oil palm with overall zonation  67
Figure 41  Crambe field  70
Figure 42  General suitability map of crambe  71
Figure 43  Suitability of Crambe with overall zonation  72
1.0 BACKGROUND & INTRODUCTION

1.1 Background
When produced in a sustainable and equitable manner, biofuels can increase Kenya’s energy self-sufficiency, support rural development and reduce deforestation and GHG emissions compared to fossil fuels. Biofuel is defined as solid, liquid or gaseous fuel obtained from relatively recently lifeless or living biological materials or as defined by Giampietro (1997), biofuel is any type of liquid or gaseous fuel produced from biomass substrates and used as a partial substitute for fossil fuels. Biofuels offer a potential renewable energy and a great market for agricultural producers (World Bank Development Report, 2008).

The output of this study is intended to assist the national authorities of Kenya to assess current land resources, conduct most effective land use planning, and focus on the feedstocks that would be suitable for production of biofuels (first generation). The study was funded by the United Nations Environment Programme (UNEP)’s Bioenergy Support Facility and led by the African Centre for Technology Studies (ACTS). The main contributors to the study were drawn from the World Agroforestry Centre (ICRAF), Kenya Agricultural Research Institute (KARI), Kenya Forestry Research Institute (KEFRI), Kenya Wildlife Service (KWS), Department of Resource Surveys and Remote Sensing (DRSR), Kenya Meteorological Department (KMD) and Ministry of Health (MoH).

1.2 Introduction
Global energy demand is growing rapidly. According to International Energy Agency (2006) without new government measures, global primary energy demand will increase by 53% between now and 2030. Over 70% of this increase will come from developing countries, led by China and India. Imports of oil and gas in the OECD and developing Asia will grow even faster than demand. World oil demand will reach 116 mb/d in 2030, up from 84 mb/d in 2005. Most of the increase in oil supply is met by a small number of major OPEC producers; non-OPEC conventional crude oil output will peak by the middle of the next decade. Global carbon-dioxide (CO2) emissions will reach 40 Gt in 2030, a 55% increase over today’s level.

Security of energy supply is another global issue. A large proportion of known conventional oil and gas reserves are concentrated in politically unstable regions, and increasing the diversity in energy sources is important for many nations to secure a reliable and constant supply of energy. Kenya, like other non-oil producing countries, has had to contend with high petroleum prices which have exerted stress on the foreign exchange resources available in the country. According to the GoK Economic Survey 2009, the total import bill for petroleum products increased by 62.3 percent in one year, from Ksh.121,712,776 million in 2007 to Ksh. 197,676 million in 2008. This is against a fall of 3 percent in the total volume of petroleum products imported over the same period, from 3,692,000 tonnes in 2007 to 3,580,000 tonnes in 2008. In the same period, Murban crude oil price peaked at US$ 137.35 per barrel in July 2008.

In the year 2009, the International Energy Outlook for 2009 (IEO, 2009) states that world energy consumption increased from 472 quadrillion British thermal units (Btu) in 2006 to 552 qBtu in 2015 and is expected to reach 678 qBtu in 2030. (IEO, 2009) Future energy technologies are geared towards minimizing global warming and climate change, regenerating and replenishing impoverished natural resources, reducing poverty and assuring adequate energy supply. For the first time in January 2008, the cost of crude oil reached US$100 a barrel, raising global concerns. Continuing near-record oil prices, fears of unaffordable and rapidly depleting sources of fossil fuel, a 26 million ton per annum wood fuel deficit for Kenya rural cooking needs, the extensive health problems caused by indoor air pollution, as well as the desire to achieve energy security and mitigate climate change have combined to focus interest in biofuel production as a cost-effective, alternative source of energy. The challenge of energy security and sustainability around the world today calls for concerted efforts at all levels (national, regional and international) with a view to identifying and developing alternative options for energy supply. Biofuel, being in principle a “renewable” energy, is seen as one of the possible alternatives.

Bioethanol and biodiesel, the two most frequently used biofuels, currently contribute about 2.2% of the global renewable energy use for electricity, heating and transport fuel (IEA Bioenergy, 2007). The
reasons for this sharp rise in use of biofuel include:

i. The growing interest in renewable energy alternatives to fossil fuels, especially as a perceived solution to the transport sector's dependency on oil.

ii. Reduced CO2 and particulate emissions.

iii. Enforcement in 2005 of the Kyoto protocol (an international agreement setting targets for industrialized countries to cut their greenhouse gas emissions, to which Kenya is a signatory)

iv. Increase in the implementation of regional and national biofuel targets by signatories to the United Nations Framework Convention on Climate Change (UNFCCC). Even though Kenya it is not obliged to reduce its greenhouse gas emissions, blending of bioethanol with petrol would contribute to the goals of this convention.

In the light of the economic disturbances resulting from price fluctuations of petroleum products in the world market, the Kenya government is focusing on reducing its reliance on imported fuels by exploiting indigenous energy resources (GoK, 2004).

1.2.1 Opportunities and Risks

Uncontrolled expansion of the biofuels sector will probably inflict a range of negative impacts on the poorest communities whose livelihoods and survival are most closely tied to the land on which they live. Nevertheless, it would be premature to presume that biofuel development can only present risks for poor people. Amongst international debates, practical examples of biofuel development creating opportunities for poor communities tend to be overshadowed by castigations of bad practice and foul play by private investors and governments. Therefore a more robust case must be made for orientation of policy and practice towards biofuel development pathways that prioritise the poor. One way in which this can be achieved is by identifying and promoting land tenure systems and policies that support pro-poor development by incorporating small-scale farmers into the biofuels boom.

Biofuels and Food

The recent boom in biofuel production has led to polarised stances on the potential of this renewable energy source. On the one side there are those who argue that bioenergy provides a sustainable solution to the world’s increasing energy needs, reduces over-dependence on a finite supply of fossil fuels, and generates a broad range of opportunities through the rejuvenation of agricultural land and markets. Critics disagree, citing increased competition between food and energy crops for land, water and other inputs - including human and financial capital, fertilizers and energy - with the poorest people most likely to be excluded, dispossessed and to suffer most. Further, they believe that expanding biofuel production endangers the very goals of climate protection and nature conservation it is meant to contribute to. While creating alternative sources of energy, we need to retain a humanly habitable and socially equitable environment, and not do more damage to earth’s self regulating systems.

Key debates linking biofuel development to land are predominantly focused on the impact of large-scale energy crop plantations on access to and use of land. Large scale plantations are being established, converting crops into biofuel to meet growing global demand. Critics of biofuel production warn that rapid expansion of the industry will provoke direct competition for land and produce negative impacts (both direct and indirect) on land and ecosystems use, and on access to land by indigenous occupants who consider it to be theirs in traditional land and community owning systems. This is particularly true of migratory pastoralists (and wildlife) that need to migrate for forage with changing seasons, rainfall and grass patterns. The linkages are complex and interrelated but can be conceptualised as follows:

1. Increasing demand for biofuels can lead to changes in land use:
   a. Changes in cropping. Crops currently grown for food, fodder, fibre etc. will be replaced with energy crops, or food crops will be used for fuel.
   b. Expansion of cultivation. Additional natural land will come under cultivation to meet global demand for biofuels.
2. Demand for biofuels can impact on access to land:
   a. Increasing demand, increasing economic value. Land users may be priced out and control over land may be shifted.
   b. Changes in cropping. New cropping patterns will displace access to land e.g. for grazing.

When assessing the use of energy crops, it is important to take account of both direct and indirect land-use changes, since these changes have a crucial impact on the greenhouse gas balance and on the risks to biological diversity. Careful land zoning and mapping, and the use of carefully selected indigenous and non-indigenous drought tolerant feedstocks, can allow Kenya to develop biofuel feedstocks without damaging the remaining forest or taking up agriculturally productive land, by regenerating and developing marginal non-food producing lands while maintaining wildlife, forests and other vital ecosystem services.

Environmental Issues

Kenya has only 1.7 per cent of its total land area under closed canopy forest cover (Kenya Forestry Master Plan, 1994). Though a very tiny fraction of the land area indeed, these forests provide crucial services to the people, the nation, and the environment. At a time when the world is confronted by climate change, forest cover can help to mitigate the effects of droughts and floods. Forests trap, store and slowly release rain water, the life blood of the economy. They support agriculture, fisheries, electricity production and urban and industrial development. Forests also produce wood and medicines, moderate climate, reduce erosion, shelter a disproportionate share of Kenya's biodiversity, and have religious and cultural significance. Forests interact closely with the water cycle. Trees act as pumps: they help water percolate into the soil, the storehouse of water, during rainy periods; and pump out water into the atmosphere, through evapo-transpiration, in dry periods. In the process, forests help keep the hydrological cycle “alive”. However, Kenya's forests have been and remain the target of over-exploitation and uncontrolled and unplanned development.

Water and Biofuels

The water sector already faces conflicts between environmental goals on the one hand and food and livelihood goals on the other. Biofuel crops are likely to add to these. The issue of how to resolve these conflicts with acceptable tradeoffs is going to be a major concern for policymakers in developing regions, particularly in Asia and Africa. For example, irrigated sugarcane could help to meet the growing demand for fuel through ethanol production. But major conflicts are already emerging between water for irrigation and environmental needs. For instance, water requirements for other uses downstream may not be met, especially during droughts, because more and more water is being withdrawn. If irrigated sugarcane for biofuel expands and more water is drawn from rivers or from shallow replenished or artesian wells, this will have serious implications for the environment and populations relying on the same resource for their livelihood.

Disadvantages

i. Pollution from runoffs

For most crops, it is standard agricultural practice to apply fertilizers such as nitrogen and phosphorus, as well as pesticides (herbicides and insecticides). However, these chemicals can wash into bodies of water and affect water quality downstream. For example, excess nitrogen washing into the Mississippi River is known to be a cause of the oxygen-starved “dead zone” in the Gulf of Mexico, in which marine life cannot survive.

ii. Stress on available water

Shifting agricultural practices to incorporate more biofuel crops will affect water quantity. The higher rate of water use will put increased pressure on water resources, more so in Kenya, which is water scarce, with demand for certain sectors such as livestock production still unsatisfied to date.
Possible Impact of a Biofuel Policy for Forestry

Negative Impacts

The population of Kenya is estimated to rise to 52 million by the year 2020 (GoK, 2008). On conservative estimates, the need for bioenergy from traditional sources will increase from 20 million cubic metres of fuelwood in 1995 to 40 million in 2020 (Kenya Forestry Master Plan, 1994). On current trends, the indigenous forests will decrease from 1.17 million hectares in 1995 to 0.93 million in 2020, and the state’s forest plantations from 164 000 hectares to 79 000 (Kenya Forestry Master Plan, 1994). This scenario will have severe social, environmental and economic consequences. With forest production and utilization already overstretched, clearing forest for biofuel crops will aggravate the situation.

Policymakers concerned about climate change are looking to biofuels as a key means of cutting greenhouse gas emissions. However, the carbon emissions associated with deforestation are greater than those avoided by using biofuels from agricultural crops (Righelato and Spracklen 2007). It is estimated that carbon emissions from conversion of rainforest, peatland, savanna or grassland for liquid biofuel production in Brazil, Southeast Asia and the US would release 17 to 420 times more CO2 than the annual greenhouse gas savings from avoidance of fossil fuels (Fargione et al. 2008).

Deforestation of the entire forest area for biofuel would result in regional decreases of precipitation and evaporation, potentially leading to sustained desertification. Research has found that it would take 75 to 93 years to see any benefits to the climate from biofuel plantations on converted tropical forestlands.¹ Until then, human will be releasing carbon into the atmosphere by cutting tropical rain forests, in addition to losing valuable plant and animal species. Conversion of peatlands and wetlands is estimated to release so much CO2 (and methane) that it could take over 600 years before any benefits are seen. It cannot be overemphasized that producing biofuels will not help countries reduce their greenhouse gas emissions if they clear their forests and/or disturb or burn peaty soils or wetlands to make room for energy crops. This leads to an increase in carbon emissions—not a decrease. Case studies in Indonesia and other places also show that sometimes the prime purpose of choosing a forested area was to evade current forestry restrictions and harvest the hard wood timber, rather than set up a sustainable and economically viable biofuel production.² Claims by biofuel promoters that Jatropha and other large scale mono-plantations of oleaginous trees increase national tree cover are only true if they are planted on severely degraded areas where no trees are left. Even then they will not replace all the ecosystem, biodiverse and social services provided by natural mixed forests.

Due to their extensive land and water demands, until and unless biofuel production is carefully and properly planned, the first and second generation biofuel feedstocks covered in this report have a strong potential to escalate the competition for land, forest and water resources, especially in areas where they are already scarce. Rushed large-scale production in sensitive areas can lead to social exclusion, environmental degradation, as well as increased greenhouse gas emissions and so undermine, rather than contribute to, Kenya’s development goals. The unique challenge for investors and policy makers is not with the feedstocks themselves, but to effectively integrate biofuel production into Kenya’s other economic, agricultural, social and environmental activities and needs in a supportive and inclusive manner. Unless this integration is well done, the public can quickly and prematurely reject all biofuels, as they will not be recognized as a credible, economic or environmentally sustainable alternative to fossil fuels and their potential positive impacts will be ignored and/or very hard to re-establish.

Positive Impacts
Introduction of biofuel crops that can grow in marginal areas will increase the total forest cover with the potential benefits of increasing tree cover and providing clean, decentralized, small-holder managed rural cooking and lighting resources. This can mitigate deforestation for agriculture and settlement that has been recorded to cause fundamental changes in the Kenya climate and hydrology cycle, with possible implications for regional ecosystem dynamics.

The environmental goal under the first Medium Term Plan of Vision 2030 is to enhance access to a clean, secure and sustainable environment. Signs of climate change are already being felt in the country as evidenced through shrinking glaciers on the mountains, occurrence of floods and droughts, and decline in water levels in the rivers and lakes. Use of petroleum fuels in the transport sector is a major contributor to greenhouse gas emissions. Smog is a growing problem in the major urban centres such as Nairobi and Mombasa. Reduction in the consumption of petroleum fuels, especially in the transport and domestic sectors, is expected to lead to a significant reduction of greenhouse gases that exacerbate global warming.

A strong focus on research, knowledge sharing, gradual careful introduction, limited size test sites, avoidance of sensitive areas, with proof of success built into gradual larger land allocation are all recommended in the accompanying National Biofuel Policy as a way of introducing biofuels into Kenya that can build an uncontroversial success story. Start slowly and cautiously and so grow faster when the realities on the ground are well understood.

1.2.3 Sustainable Biofuels
Many initiatives are going on globally to ensure that biofuels are grown sustainably (WBA, 2010; RSB, 2008). At the heart of these initiatives is ensuring that biofuels deliver on their promises of climate change mitigation, economic development and energy security without causing environmental and/or social damage such as deforestation and food insecurity. On a project level, a number of criteria are being worked on. For example Roundtable on Sustainable Biofuels (RSB) has developed 12 principles and criteria (EPFL Energy Center, 2008). They describe the fundamental requirements of sustainable biofuel production, such as the necessity to consult local stakeholders; the greenhouse gases performance; the conservation of important ecosystems; and the mitigation of food insecurity in the region of operation.

Lessons learned from other countries shows that sustainable biofuel production can only be achieved by ensuring strict environmental legislation at all levels. For example in the State of Sao Paulo, Brazil there is less use of chemicals and fertilizers, avoidance of field burning, improvements in water efficiency, and little or no irrigation. Land currently used to grow sugar cane is far from the Amazon. Biodiversity is protected through legislation for legal biodiversity reserves (although some states need better enforcement). Being the world leader in biofuels, Brazil has initiated Agro-Ecological Zoning (AEZ) for future sugarcane expansion, and a voluntary sustainability certification system is in place (Oeko-Institut and UNEP, 2009).

China, which is the third-largest producer in the world of first- and second- generation biofuels, has developed and tested a decision tree for the use of degraded land for biofuel feedstock production (Oeko-Institut and UNEP, 2009). The factors taken into account for feedstock suitability for degraded land include: the integration of sustainable cropping systems; cost competitiveness and market demand; and competition with other land-uses.

In both the Brazilian experience as well as the Chinese case study, the importance of mapping and zoning is the main emphasis. Zoning provides a tool for decision making when deciding on the type of biofuel and a suitable area to produce feedstock.

1.3 History of Suitability Mapping in Kenya
The history of suitability mapping for biofuel production in Kenya dates from about 5 years ago when the World Agroforestry Centre (ICRAF) used a GIS modelling approach to produce a suitability map of *Jatropha curcas* for the Vanilla Foundation, an NGO working on the promotion of biofuel production
and development. A year later, Endelevu Energy, a consultant firm, also commissioned the ICRAF GIS Unit to produce biofuel suitability maps for 11 biodiesel and bioethanol feedstocks in Kenya, dubbed “A Roadmap to Biofuel in Kenya” (GTZ & GOK, 2008). Unlike the previous study by ICRAF for the Vanilla Foundation, the GTZ-commissioned study went further than just providing suitability maps, and also included other parameters such as suitability outside the protected areas and within arable and non-arable lands. In this new study, zoning is expanded further to include suitability areas outside wetlands, areas of high biodiversity value for conservation outside the protected areas, natural animal corridors, and conflict areas. And for investment prioritization, the mapping team adopted the optimum agronomic characteristics of some of the biofuel crops (caster, croton, jatropha, sugarcane and sweet sorghum) to evaluate suitability levels.

Data used in these studies were sourced from both global and national GIS datasets, which complemented and supplemented each other for quality and accuracy of the suitability map production. Furthermore, the resulting outputs were calibrated using specific national datasets and relevant information from research institutions such as KARI, KEFRI, ACTS and ICRAF. Experience from the Chinese study indicated that a “ground truthing” exercise, carried out to compare the findings of global and national GIS data from “top-down” mapping with those from “bottom-up” field trips, revealed that there are situations in which the top-down approach leads to erroneous results. Using more recent data at higher spatial resolution could help to reduce this error, but “ground truthing” seems to be necessary to validate mapping based on remote sensing.

1.4 Objective of the Study

To assist the national authorities of Kenya in better planning of land use and assessment of the land resources and feedstocks suitable for production of biofuels (first generation). This study is aimed at the aforementioned issues to carry out agro-climatical and environmental zoning of the country to map out different land uses, match different feedstocks to suitable site and identify and map out high value conservation areas, in a view to underpin the national biofuels policy that has been drafted. This will ensure that biofuel development will reconcile the economic productivity with environmental preservation and food production.

Specific Objectives

1. Develop protocols for agro-climatic and environmental zoning for biofuel production in Africa.
2. Delineate nationally and internationally recognized and non-recognized biodiversity conservation areas including important bird areas.
3. Delineate important wetlands, water catchment areas and slopes of more than 45%.
4. Identify and delineate mapped important wildlife corridors.
5. Identify and map main land uses (crop lands, pastoral areas and Wildlife movement paths [3km width]).
6. Develop feedstock suitability maps based on the biotic and edaphic factors.

Main Guidelines

Data collection and zoning will follow the following guidelines:

i. Exclude areas for biofuel cultivation such as areas of high biodiversity and conservation value, protected areas, forests, river basins and wetlands; human-wildlife conflict areas and wildlife movement corridors (3km width);
ii. Avoid competition with food production;
iii. Indicate areas with agricultural potential for production of biofuel crops or feedstocks.
2.0 METHODOLOGY

Feedstocks covered in this study are sugar cane, sweet sorghum, cassava, *Jatropha curcas*, *Croton megalocarpus*, caster, cotton, sunflower, canola (rapeseed), coconut, oil palm and *Crambe abyssinica*. The process of biofuel feedstock suitability mapping is founded on principles of land evaluation developed by FAO in 1976: matching of the ecological and management requirements of relevant land use with land qualities, whilst taking local economic and social conditions into account (FAO, 1976).

Instead of targeting a variety of crops and selecting one or more with higher socio-economic returns and optimal biophysical compliance, the process zeroes-in one crop at a time, and land areas are selected with both optimal biophysical and optimal socio-economic scores.

THE OVERALL METHOD ENTAILS TO SERIES OF ACTIVITIES

2.1 Data Collection and Compilation

This involved (i) identification of key biophysical data sets that would contain biofuel crops’ agronomic characteristics such rainfall, temperature, altitude, and soil; plus any management-related data sets such as protected and high biodiversity areas, natural animal corridors and conflict areas, land for food and cash crops, arable and non-arable areas; and (ii) compilation of agronomic characteristics information for all of the identified biofuel crops. By accessing both global and national databases, all the biophysical and socio-economic datasets were collected and compiled. A “ground truthing” exercise, carried out to confirm the global and national GIS data and collect other required data. GPS reading were collected to construct the maps. Experts from KARI, KEFRI and ACTS sourced and compiled agronomic characteristics data and information for 11 biofuel crops and passed these to the mapping team.

2.2 Data Processing to Produce Suitability Areas

From each of the biophysical datasets, a range of values for each biofuel crop is extracted as provided by agronomic characteristics. This is then overlaid in GIS via a Boolean Algebra Model giving continuum suitability and 250 colors/grey levels, which cannot be easily interpreted by human eye.

For example, *Jatropha* suitability = \( T = T_{\text{em}} \cap (R_{\text{em}} \cap A_{\text{em}} \cap S_{\text{em}}) \)

\( \begin{array}{c}
\text{T = Temperature; } t_{\text{min}} = \text{minimum temperature value; } t_{\text{max}} = \text{maximum temperature value; } \\
(s_{\text{min}}, y_{\text{min}}) = \text{location of temperature value; } \\
R_{\text{em}}, A_{\text{em}}, S_{\text{em}} = \text{rainfalls; } A = \text{altitude}. 
\end{array} \)

The grey levels are simplified as 1 and 0 to show areas of suitability and non-suitability respectively. This process was further expanded in some of biofuel crops (caster, croton, *jatropha*, sugarcane and sweet sorghum) to include suitability levels by classifying agronomic characteristics into 3 levels of suitability (high, moderate and marginal) according to the range and optimal growing conditions. To be considered highly suitable, the area must fit all of the optimal growing conditions. Moderately suitable areas include locations with at least one optimal agronomic parameter, such as rainfall. Marginally suitable areas fall within the range of agronomic conditions, but not the optimal ones (Endelevu Energy, ICRAF and KEFRI, 2009).

2.3 Calibration of Suitability Map with Field Data

Research findings in different journals provide different agronomic ranges of crops, sometimes making it difficult to get a definitive answer for each crop’s requirements. Besides, agronomic documented information about some crops depict different farm/crop management inputs which make it more difficult to apply the aforementioned requirements globally. It was therefore important to calibrate the suitability maps with biofuel crops and herbarium databases in Kenya. For example overlaying *Jatropha* marked herbarium data from Museums of Kenya with a suitability map formed a better calibration tool in this exercise. Using expertise, guidelines and secondary information, several biofuel suitability outputs were verified and calibrated to enhance mapping quality and accuracy. Even so, it must be pointed out that even within the ‘highly suitable areas’ on this scale, small pilot projects have already demonstrated that for many...
crops, and in particularly sensitive ones like Jatropha, the high level of suitability can change within very small distances of within 10 – 20 kilometres due to the great variances in Kenya’s soils, landscapes and micro climates. With so many unknown variables, ‘ground truthing’ data collected from pilot sites is key before agreeing and launching a large scale plantation in any area.

2.4 Integration of Suitability Layers with Socio-economic Data

The objective is to establish the location and quantity of land areas that would be available for each biofuel crop investment in Kenya, using key management and conservation variables such as:

i. Areas outside gazetted establishments (forest, parks, and game reserves),

ii. Areas within and outside food and cash crops farming, and

iii. Within arable and non arable land.

iv. Wetlands and areas of high biodiversity value for conservation outside the protected areas,

v. Natural animal corridors (animal movement paths (3km width))

vi. Human-conflict areas

By conversion of each management and conservation variable into raster and Boolean standardized format, and overlaying them with biophysical-based suitability layers, a series of suitability maps for each feedstock within different zones were produced. Areas were derived by multiplying value counts in each raster by pixel area.

Level of Suitability

To get the levels of Suitability, all biophysical data for modeling are classified into three 3 portions (Table 1): P1-lower range, P2-optimal range, and P3-upper range. They are then overlayed under grid tool called combine, giving pixels with P1, P2, and P3. For example, highly suitable areas must have all P2 pixels and at least 2 or 1 P2 depending on the number factors used.

Table 1 Suitability levels of jatropha, sugarcane, castor, croton and sweet sorghum

<table>
<thead>
<tr>
<th>Agronomic Parameters</th>
<th>Overall range</th>
<th>Optimal Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual temperature (°C)</td>
<td>12-32</td>
<td>19.3-27.2</td>
</tr>
<tr>
<td>Annual Rainfall (mm)</td>
<td>480-2380</td>
<td>1000-2000</td>
</tr>
<tr>
<td>Altitude (m)(diurnal temperature/humidity dependent)</td>
<td>0-1650</td>
<td></td>
</tr>
</tbody>
</table>

These range are divided into 3 partitions P1, P2 and P3

| Jatropha: All agronomic parameters are partitioned into three classes (P1, P2, P3) |
|------------------------|-------------|-------------|-------------|
| Agronomic Parameters   | P1          | P2          | P3          |
| Annual temperature (°C) | 12-19.3     | 19.3-27.2   | 27.2-32     |
| Annual Rainfall (mm)   | 480-1000    | 1000-2000   | 2000-2380   |
| Altitude (m)           | 0-1650      |             |             |
| Soil                   | Well drained soils and no swampy areas. pH > 6.5 |

When overly these agronomic variables under grid tool called Combine, in ArcView 3.2a (Jenness Enterprises, 2006), we get resultant pixels with 2 P2 (for Highly suitable); 1P2 (for Moderately suitable), and the rest marginally suitable (Endelevu Energy, 2009)

3 Optimal = 600-800mm in the first five/six months, then two – three month dry period before the rains. Each plant needs 6 litres a week to establish.
These range are divided into 3 partitions P1, P2 and P3

### Sugar cane

<table>
<thead>
<tr>
<th>Agronomic Parameters</th>
<th>Overall range</th>
<th>Optimal Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual temperature (°C)</td>
<td>12-38</td>
<td>20-30</td>
</tr>
<tr>
<td>Annual Rainfall (mm)</td>
<td>1000-1800</td>
<td>1200-1800</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td>0-1500</td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td>Loam to clay Soil</td>
<td></td>
</tr>
</tbody>
</table>

When overly these agronomic variables under Grid tool called Combine, in ArcView 3.2a (Jenness Enterprises, 2006), we get resultant pixels with 2 P2 (for Highly suitable); 1P2 (for Moderately suitable), and the rest marginally suitable.

### Sugar cane: All agronomic parameters are partitioned into three classes (P1, P2, P3)

<table>
<thead>
<tr>
<th>Agronomic Parameters</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual temperature (°C)</td>
<td>12-20</td>
<td>20-30</td>
<td>30-38</td>
</tr>
<tr>
<td>Annual Rainfall (mm)</td>
<td>1000-1200</td>
<td>1200-1800</td>
<td>&lt;1800</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td>0-1500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td>Loam to clay soils</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Castor

<table>
<thead>
<tr>
<th>Agronomic Parameters</th>
<th>Overall range</th>
<th>Optimal Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual temperature (°C)</td>
<td>15-39</td>
<td>20-30</td>
</tr>
<tr>
<td>Annual Rainfall (mm)</td>
<td>400-2000</td>
<td>750-1000</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td>0-2000</td>
<td>300-1800</td>
</tr>
<tr>
<td>Soil</td>
<td>Well drained soils friable, sandy loam soils</td>
<td></td>
</tr>
</tbody>
</table>

When overly these agronomic variables under Grid tool called Combine, in ArcView 3.2a (Jenness Enterprises, 2006), we get resultant pixels with 3 P2 (for Highly suitable); 2P2 (for Moderately suitable), and the rest marginally suitable.

### Castor: All agronomic parameters are partitioned into three classes (P1, P2, P3)

<table>
<thead>
<tr>
<th>Agronomic Parameters</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual temperature (°C)</td>
<td>15-20</td>
<td>20-30</td>
<td>30-39</td>
</tr>
<tr>
<td>Annual Rainfall (mm)</td>
<td>400-750</td>
<td>750-1000</td>
<td>1000-2000</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td>0-300</td>
<td>300-1800</td>
<td>1800-200</td>
</tr>
<tr>
<td>Soil</td>
<td>Well drained soils friable, sandy loam soils</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Croton

<table>
<thead>
<tr>
<th>Agronomic Parameters</th>
<th>Overall range</th>
<th>Optimal Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual temperature (°C)</td>
<td>11-26</td>
<td>16-22</td>
</tr>
<tr>
<td>Annual Rainfall (mm)</td>
<td>800-1900</td>
<td>1000-1400</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td>1200-2450</td>
<td>1200-1600</td>
</tr>
<tr>
<td>Soil</td>
<td>Light deep and well drained soils</td>
<td></td>
</tr>
</tbody>
</table>
When overly these agronomic variables under Grid tool called Combine, in ArcView 3.2a (Jenness Enterprises, 2006), we get resultant pixels with 3 P2 (for Highly suitable); 2P2 (for Moderately suitable), and the rest marginally suitable.

**Sweet Sorghum**

<table>
<thead>
<tr>
<th>Agronomic Parameters</th>
<th>Overall range</th>
<th>Optimal Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual temperature (°C)</td>
<td>17-40</td>
<td>22-35</td>
</tr>
<tr>
<td>Annual Rainfall (mm)</td>
<td>350-2380</td>
<td>400-600</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td>0-2500</td>
<td>Pellic vertisols</td>
</tr>
</tbody>
</table>

When overly these agronomic variables under Grid tool called Combine, in ArcView 3.2a (Jenness Enterprises, 2006), we get resultant pixels with 2 P2 (for Highly suitable); 1P2 (for Moderately suitable), and the rest marginally suitable.
3.0 RESULTS

3.1 Biofuel Suitability per Region
To assess biofuel potential in different regions of Kenya, a map was produced showing the number of feedstock suitable per scene (Fig. 1). The result of this comparison shown that coast, central and western have the highest potential for feedstock production given the high number of feedstocks they can support. Northern and south western Kenya has the lowest potential.

Figure 1 Number of Biofuel Crops Suitable per Scene
Three bioethanol feedstock covered in the current study were sugarcane, sweet sorghum and cassava.

### 3.2.1. Sugarcane

**Scientific name:** *Saccharum spp*

**Kiswahili name:** *Miwa*

Sugar cane grows in the tropics and provides half of the world’s sugar. Sugarcane is still one of the most important crops in Kenya alongside tea, coffee, horticultural crops and maize. It directly supports 200,000 small-scale farmers who supply over 80% of the cane milled by the sugar companies. An estimated 6 million Kenyans derive their sustenance out of sugar; and the crop provides direct employment to over 40,000 workers (Kenya Sugar Board, 2009). About 304 accessions have been collected in Western and Nyanza provinces of Kenya but only 17 land races are stored in the field bank by the Kenya Genetics Resource Centre.

#### Plant characteristics

Sugarcane is a tall grass-like species that has stems referred to as canes. It is one of the few plants in the world that stores its carbohydrates in the form of sugar. The stems can be either self-stripping (i.e. they shed their leaf sheathes) or non-stripping (Acland, 1971). The inflorescence called “the arrow” is a loose, white, feathery panicle. Sugar cane fuzz or seed is difficult to collect because it is light and easily blown away by wind.

#### Growth conditions

- **Maturity time:** 13-24 months
- **Temperature range:** 12-38°C, with optimum of 20-30°C
- **Rainfall:** 1000-1800 mm, and an optimum 1200-1800
- **Altitude:** 0-1500m above sea level
- **Soil types:** loam to clay-cambred beds. Ditches or furrows must be formed in clay soils to lead off surplus water

#### Crop husbandry

Fuzz is predominately used by breeders to develop new sugarcane varieties. Stem cuttings, called sets, are used to propagate sugarcane commercially (Fauconnier, 1993 and Acland, 1971). These are buried in furrows spaced at 1.2-1.8m between rows. Weeding is done three to four times before harvesting. When the cane is cut for the first time, ratoons develop which can be used as the second or third crop. However since the sugar quality reduces with subsequent ratoon crops, it is discouraged for industrial applications. Harvesting of sugarcane is recommended during the dry season since this is when the sugar content is highest (Fauconnier, 1993). After harvesting the crop, it must be transported to the sugar factory within 48 hours.

#### Pests and diseases

Sugarcane scales cause up to 40% yield loss. They can be controlled by use of insecticides. Nematodes also affect the performance of sugarcane because they interfere with the roots. Other pests that have affected sugarcane in Kenya include white scale, white gnats and termites. Sugarcane diseases that cause concern in production include ratoon stunting disease, smut, mosaic, yellow wilt and leaf spots.

#### Utilization

Sugar is the most important product of sugarcane. Over the last four decades, sugar consumption in Kenya has continued to grow rapidly, thereby outstripping supply. While sugar production increased from 368,970 tones in 1981 to 520,404 tones in 2007, domestic consumption increased even faster, rising from 324,054 tones to 741,190 tones over the same period. Consequently, Kenya has increasingly become a net
importer of sugar with imports rising from 4,000 tones in 1984 to 230,011 in 2007 (Kenya Sugar Board, 2009) (Table 2).

Table 2 Sugar production, consumption imports and exports, 2001-2008 (Mt)

<table>
<thead>
<tr>
<th>YEAR</th>
<th>Production</th>
<th>Consumption</th>
<th>Imports</th>
<th>Exports</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>377,438</td>
<td>630,065</td>
<td>249,336</td>
<td>3,600</td>
</tr>
<tr>
<td>2002</td>
<td>494,249</td>
<td>652,129</td>
<td>129,966</td>
<td>12,046</td>
</tr>
<tr>
<td>2003</td>
<td>448,489</td>
<td>663,780</td>
<td>182,225</td>
<td>11,300</td>
</tr>
<tr>
<td>2004</td>
<td>516,803</td>
<td>669,914</td>
<td>164,020</td>
<td>11,580</td>
</tr>
<tr>
<td>2005</td>
<td>488,997</td>
<td>695,622</td>
<td>167,235</td>
<td>21,760</td>
</tr>
<tr>
<td>2006</td>
<td>475,670</td>
<td>718,396</td>
<td>166,280</td>
<td>13,533</td>
</tr>
<tr>
<td>2007</td>
<td>520,404</td>
<td>741,190</td>
<td>230,011</td>
<td>20,842</td>
</tr>
<tr>
<td>2008</td>
<td>517,667</td>
<td>751,523</td>
<td>218,607</td>
<td>44,332</td>
</tr>
</tbody>
</table>

Biofuel potential
Sugar can juice, molasses and bagasse all have potential as feedstocks in ethanol and biofuel production. The area under cane in Kenya is about 123,622 hectares of which, 111,189 ha is under the smallholder and 12,433 under nucleus estates. The annual production ranges from 400,000 - 490,000 metric tonnes (MT). However, production decreased from 494,249 MT in 2002 to 448,489 MT in 2003. This decrease in output was mainly attributed to reduction in the area under cane production. The total national demand for Sugar currently stands at about 600,000 MT. The annual deficit of about 200,000 MT is met by imports, of which 111,000 MT is refined sugar and 89,000 MT is raw/mill sugar.

Environmental Suitability and Agro-Environmental Zoning for Sugarcane
The suitability mapping is based on sugarcane grown under natural conditions and does not include irrigated sugarcane. Based on the environmental suitability (average rainfall, temperature and soils), the sugar belt is concentrated in western Kenya, the coastal strip and parts of eastern Kenya (Fig. 3) covering a total area of 17,332 km2 which is about 3% of the total Kenya surface area (Table 3). This suitable area reduces when other factors are considered. For example, removing the protected areas out of the general suitability reduces the land available for sugarcane cultivation to 15,916 km2 which is 2.8% of the total Kenya surface area (Table 3, Appendix 2). Other areas that have been zoned out are wildlife conflict areas, wetland areas, important bird areas, slopes of more than 45% and animal movement paths. This leaves the total land available for sugarcane growing at 12,591km2 or 2.2% of the total Kenya surface area (Fig. 4, Table 3). The study has shown that the entire sugar belt is within the food and cash crop area (Appendix 2). Based on crop productivity, the study also attempted to categorize the suitable areas into varying suitability levels as low, moderate and highly suitable (Fig. 5). The suitability level took into account the fact that though the general rainfall requirement is between 1000 – 1800mm per annum, optimal rainfall average is between 1200 – 1800mm per annum (Table 1).
Table 3 Sugarcane suitability

<table>
<thead>
<tr>
<th>Suitability and Zonation</th>
<th>Sugar cane area (km²)</th>
<th>% of Kenya land surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>General suitability</td>
<td>17,332</td>
<td>3.0</td>
</tr>
<tr>
<td>Suitable outside protected area</td>
<td>15,916</td>
<td>2.8</td>
</tr>
<tr>
<td>Suitable within Food Crop areas</td>
<td>12,912</td>
<td>2.3</td>
</tr>
<tr>
<td>Suitable within Cash Crop areas</td>
<td>1,545</td>
<td>0.3</td>
</tr>
<tr>
<td>Suitable outside food and cash crops areas</td>
<td>1,458</td>
<td>0.3</td>
</tr>
<tr>
<td>Suitable within cultivated lands</td>
<td>14,457</td>
<td>2.5</td>
</tr>
<tr>
<td>Suitable within Non-cultivated areas</td>
<td>1,458</td>
<td>0.3</td>
</tr>
<tr>
<td>Suitable outside Wildlife Conflict areas</td>
<td>13,052</td>
<td>2.3</td>
</tr>
<tr>
<td>Suitable outside Wetland areas</td>
<td>12,728</td>
<td>2.2</td>
</tr>
<tr>
<td>Suitable outside Animal movement paths (3km)</td>
<td>12,591</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Figure 3 General suitability map of sugarcane
Figure 4 Sugarcane suitability map with overall zonation
Figure 5 Sugarcane suitability levels with overall zonation.
3.2.2 Sweet Sorghum

Scientific name: *Sorghum bicolor (vulgare)*
Kiswahili name: *Mtama*

Indigenous sorghum was an important cereal crop long before maize became the staple food of Kenya. The Kenya Genetic Resource Centre has 5672 accessions of sorghum collected from Kenya, of which 2407 were initially collected by the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) then donated to the center and thereafter 3265 were collected. Local varieties have either open or compact panicles. Although several sorghum varieties exist, the scientific name given for all cultivated sorghum is *Sorghum bicolor*. Sweet sorghum’s history can be traced back to Egypt but it was introduced in Kenya for its dual product, grain and sweet juice (Lapedes, 1971).

Plant characteristics

It is an annual crop that is relatively drought tolerant. The plant grows between 0.6 to 5 m tall and the stem has sweet and juicy pith. Sweet sorghum has smooth glossy or waxy surfaces which fold and roll up during drought. The inflorescence is a panicle and the plant is self pollinated.

Growth conditions

- **Maturity period:** 4 months
- **Temperature range:** 17-40°C (sweet sorghum can germinate at 17°C but requires warm temperatures for optimal harvest), and optimum of 22-35°C
- **Rainfall:** 350-2380mm, and optimum of 400-600 mm
- **Altitude:** 0-2500 metres above mean sea level.
- **Soil types:** Well drained soils with good supply of nutrients (fertilizer can supply these nutrients). Clay, clay loam and sandy loam soils.

Crop husbandry

The seed is cultivated in rows spaced 50-60cm apart with hill to hill spacing of 12-15cm (Rao et al, 2008). Weeds in sorghum can be controlled through chemical sprays (pre-emergence herbicides are applied at most one day after sowing) and mechanically until the crop is 35-40 days old. The crop is physiologically mature when a black spot appears on the grain at the lower end. The grain can be harvested either manually or using a combine. The sweet sorghum stalks can be harvested for juice when its brix reaches 16-18%. This is measured using a hand refractometer (Rao et al, 2008).

Pests and diseases

Major pests affect sorghum at different stages of growth and they include cutworms, armyworms, wireworms and seed beetles. Shoot flies, stem borers, shoot bug and sugarcane aphids have been reported to attack sweet sorghum in India. In areas where the humidity and rainfall are high sweet sorghum suffers from foliar diseases such as leaf blight and dwarf mosaic. Lodging of the crop can also be as a result of charcoal rot (Rao et al, 2008 and Acland, 1971).

Utilization

Sorghum is mainly grown in the lower potential districts in Kenya where its role as a key food security item has been recognized (MoA, 2008a). Food such as cereals, snacks, bread and porridge (fermented and unfermented) can be made from sorghum grain. The stalks can be used as animal fodder and in the manufacture of paper and wallboards. Alcohol that can be used as a beverage or biofuel is made from the juice or grain. Sorghum production in Kenya for 2003-2007 is presented below (Table 4).
Table 4 Sorghum production, 2003-2008

<table>
<thead>
<tr>
<th>Year</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (Ha)</td>
<td>148,985</td>
<td>123,155</td>
<td>122,368</td>
<td>163,865</td>
<td>155,550</td>
<td>104,041</td>
</tr>
<tr>
<td>Production (Bags)</td>
<td>1,413,505</td>
<td>961,034</td>
<td>1,668,081</td>
<td>1,457,503</td>
<td>1,637,391</td>
<td>-</td>
</tr>
<tr>
<td>Production (Tons)</td>
<td>127,343</td>
<td>86,580</td>
<td>150,127</td>
<td>131,188</td>
<td>147,365</td>
<td>147,365</td>
</tr>
<tr>
<td>Consumption (Bags)</td>
<td>1,342,000</td>
<td>1,100,000</td>
<td>1,425,000</td>
<td>1,510,000</td>
<td>1,551,525</td>
<td>-</td>
</tr>
<tr>
<td>Total Value (Billions Ksh.)</td>
<td>2.67</td>
<td>2.11</td>
<td>2.84</td>
<td>1.83</td>
<td>1.62</td>
<td>-</td>
</tr>
</tbody>
</table>


Biofuel potential

Like sugar cane, sweet sorghum (Sorghum bicolor L. Moench) is a C4 plant characterized by a high biomass- and sugar-yield and a high photosynthetic efficiency. As such, sweet sorghum is a high potential multipurpose crop where the seed can be used as flour and poultry feed, the juice to drink and make wine, vinegar and other fermented drinks, and the leftover biomass used for boards and packaging. It has the advantage of greater altitude range (minimum temperatures 17°C) and lower water use (4 times less than sugarcane), greater drought tolerance and a shorter maturity time (3-6 months) than sugarcane with ¼ the cost of production. Current processing in India extracts more sugar with less wastewater and energy use and with higher alcohol yields than sugar cane. It contains approximately equal quantities of soluble (glucose and sucrose) and insoluble (cellulose and hemicellulose) carbohydrates. The ethanol has superior quality, lower sulphur content, high octane rating and is automobile friendly (up to 25% blending). Bagasse obtained after juice extraction has higher biological value and is rich in micronutrients; and is used as feed or for power cogeneration.

The advantage of sweet sorghum for an arid and semi-arid country like Kenya is that it can be grown extensively in the central and western and northwestern regions on land that is less suitable for other foodstuffs. Of the many crops being investigated for energy and industry, sweet sorghum can be considered as one of the most promising crops for the production of ethanol.

Environmental Suitability and Agro-Environmental Zoning for Sweet Sorghum

Based on the environmental suitability (average rainfall, temperature and soils) sweet sorghum has a very wide range from western, central, eastern and coastal regions of Kenya (Fig. 7). The total suitable area is estimated at 263,965 km², which is about 46.4% of the total Kenyan surface area (Table 5); which makes sweet sorghum the feedstock with the widest suitable area. When the protected areas are removed from the general suitable area, the land available for sweet sorghum cultivation reduces 206,574 km² which is 36.33% of the total Kenya surface area (Table 5, Appendix 2). On zoning out wildlife conflict areas, wetland areas, important bird areas, slopes more than 45% and animal movement paths, the total land that remains available for growing sweet sorghum reduces to about 174,446 km² or 30.6% of the total Kenya surface area (Table 5, Fig. 8). The wide spread of suitability for sweet sorghum covers land are taken by national parks and game reserves such as Tsavo, Maasai Mara, Samburu, Meru and others. While sweet sorghum poses less competition to cash crops in terms of the area of coverage (Appendix 2), it is all found in arable lands whether cultivated or uncultivated (Appendix 2). Based on crop productivity, the highly suitable areas are scattered in agriculturally marginal to medium potential areas (Fig. 9).
Table 5 Sweet sorghum suitability

<table>
<thead>
<tr>
<th>Suitability and Zonation</th>
<th>Sweet sorghum area (Km²)</th>
<th>% of Kenya land surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>General suitability</td>
<td>263,965</td>
<td>46.4</td>
</tr>
<tr>
<td>Suitable outside protected area</td>
<td>206,574</td>
<td>36.3</td>
</tr>
<tr>
<td>Suitable within Food Crop areas</td>
<td>53,204</td>
<td>9.3</td>
</tr>
<tr>
<td>Suitable within Cash Crop areas</td>
<td>4,029</td>
<td>0.7</td>
</tr>
<tr>
<td>Suitable outside food and cash crops areas</td>
<td>149,260</td>
<td>26.2</td>
</tr>
<tr>
<td>Suitable within cultivated lands</td>
<td>57,332</td>
<td>10.1</td>
</tr>
<tr>
<td>Suitable within Non-cultivated areas</td>
<td>149,260</td>
<td>26.2</td>
</tr>
<tr>
<td>Suitable outside Wildlife Conflict areas</td>
<td>182,758</td>
<td>32.1</td>
</tr>
<tr>
<td>Suitable outside Wetland areas</td>
<td>179,260</td>
<td>31.5</td>
</tr>
<tr>
<td>Suitable outside Animal movement paths (3km)</td>
<td>174,446</td>
<td>30.6</td>
</tr>
</tbody>
</table>
Figure 7 General suitability of sweet sorghum
Figure 8 Sweet sorghum suitability with overall zonation
Figure 9 Suitability levels of sweet sorghum
3.2.3 Cassava
Scientific name: *Manihot esculante*
Kiswahili name: *Muhogo*
This is one of the widely grown crops in East Africa due to its drought tolerant characteristic. Although breeding of cassava in East Africa started in Tanzania, the Kenya Agricultural Research Institute (KARI) Stations in Western and Eastern Kenya have been involved in breeding and dissemination of cassava hybrids. The main criterion for developing cassava hybrids in Kenya has been resistance to pest and diseases (Mbwika and Kamau, 2002). Testing and screening for diseases is another major programme carried out in KARI because cassava is vegetatively propagated so farmers tend to get their own seed sources. The Kenya Genetics Resource Center has collected 108 accessions of cassava.

Plant characteristics
Cassava can grow up to 4.5m high with a woody stem having several branches. Although the plant produces flowers and seed, field propagation is mostly done using stem cuttings. Cassava is grown for its tubers which are a rich source of carbohydrates. The tubers are swollen lateral roots measuring up to 15cm in diameter and up to 90cm in length.

Growth conditions
- Maturity time: 6-9 months
- Temperature range: 16-30°C
- Altitude: 0-1500m above sea level
- Rainfall: 580-1500 mm
- Soil requirements: Free draining rock free soils of medium fertility. Rocks impede tuber expansion.

Crop husbandry
Cassava is propagated vegetatively by use of stem cuttings. These cuttings must have a node and they may be planted at 45° or laid flat in a hole about 7.5-10 cm deep. Planting is done on ridges to facilitate harvesting. The recommended plant spacing is 0.9m by 1.5m for a pure stand. Mechanical weeding needs to be done throughout the crops’ life to ensure high yields (Anselm et al, 2005).

Intercropping cassava with other crops
Studies on intercropping cassava with annual crops have not been done, however for erosion control cassava has been intercropped with trees. Soil erosion and runoff were significantly reduced when cassava was grown on soil mounds staggered in the midst of Leuceana spp. and Eucalyptus spp. (Ghosel et al, 1989).

Pests and diseases
Porcupines, different types of rodents, baboons, monkeys and wild pigs cause major field losses. Other major pests include cassava hornworm, cassava mites, thrips, gall midges, root knot nematodes, mealy bugs, scale insects, variegated grasshopper, white flies, termites and spider mites. Mechanical, cultural and chemical means are used to control a number of cassava pests and diseases. While propagated by white fly, the causal agent of African Mosaic Virus disease is unknown. Various pathogens are associated with cassava stem rot. Other major cassava diseases include leaf spots, brown spot, bacterial blight and brown streak virus disease (Githunguri, 2010, Mbwika and Kamau, 2005, and Acland, 1971).

Utilization
Processing of cassava in Kenya is at its infant stages with most of it done in micro processing plants (Mbwika and Kamau, 2002). The main processed products are cassava chips, dried chips, flour and starch. In western Kenya, cassava comes second to maize as a food crop, and is a staple food in Coast Province. Cassava is an important backup food source in times of drought because of its tolerance to water stress. Its leaves and
Tubers are used as a vegetable. The tubers are boiled after peeling of the outer layer and its flour is used in porridge, soups and ugali. Cassava crisps are slowly gaining popularity in Kenya. Cassava is also used as a base in canned foods, ice cream, biscuits, confectionary and pharmaceuticals. Cassava is mainly grown in the lower potential districts in Kenya (MoA, 2008a). Cassava production in Kenya for 2003-2007 is presented below (Table 6).

**Table 6 Cassava production, 2003-2007**

<table>
<thead>
<tr>
<th>Year</th>
<th>Area (Ha)</th>
<th>Production (Tons)</th>
<th>Total Value (Billions Ksh.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>53,297</td>
<td>421,317</td>
<td>3.2</td>
</tr>
<tr>
<td>2004</td>
<td>56,010</td>
<td>388,713</td>
<td>3.1</td>
</tr>
<tr>
<td>2005</td>
<td>68,320</td>
<td>566,400</td>
<td>3.7</td>
</tr>
<tr>
<td>2006</td>
<td>68,502</td>
<td>656,633</td>
<td>4.3</td>
</tr>
<tr>
<td>2007</td>
<td>53,610</td>
<td>397,705</td>
<td>5.6</td>
</tr>
</tbody>
</table>

*Source: Ministry of Agriculture: Economic review of Agriculture 2008*

**Biofuel potential**

Cassava (Manihot esculenta) has important use as a staple foodstuff providing over 50% of starch intake in sub-Saharan Africa. It is a perennial woody shrub with up to 32% (fresh) starch content. The benefits of using cassava as a raw material for ethanol production are that it can be planted on marginal lands where other agricultural crops such as sugarcane, rice, wheat and corn cannot be grown well. Besides, it has high tolerance to drought because it can survive even during the dry season where soil moisture is low but humidity is high. It thrives better in poor soils than any other major food plant. 160-180 litres of hydrous bioethanol can be generated from one tonne of cassava.

It matures over 12 – 24 months. New disease-resistant types are being introduced. Cassava is the second main staple food at the Coast and currently yields 5-10t/ha, while the potential is 32t/ha. Therefore, wide areas of little used land can be utilized for cultivation. Fertilization is rarely necessary and it requires minimal maintenance. A “food versus energy” campaign can cause biofuel to lose out to food; however a “food and energy” agenda will promote the use of cassava as a source of biofuel.

**Environmental Suitability and Agro-Environmental Zoning for Cassava**

The suitability mapping is based only on cassava grown under natural conditions and not under irrigation. Based on the environmental suitability (average rainfall, temperature and soils) cassava has a very wide range of suitability (Fig. 11). It can be grown across the southern half of Kenya: the Western, Coastal and semi-arid (Eastern) regions of Kenya have the highest production in that order (Fig. 11). The total suitable area is 103,044km² which is about 18.1% of the total Kenya surface area (Table 7). When the protected areas area removed out of the general suitability the land available for growing cassava is 81,312km² or 14.3% of the total Kenya surface area (Table 7, appendix 2). When other important areas such as wildlife conflict areas, wetland areas, important bird areas, slopes more than 45% and animal movement paths area zoned out the total land available for growing cassava is 66,092km² or 11.6% of the total Kenya surface area (Table 7, Fig. 12). While cassava shows less competition with cash crops except in the coastal area (Appendix 2), it is all found in arable lands whether cultivated or uncultivated (Appendix 2).
Table 7 Cassava suitability

<table>
<thead>
<tr>
<th>Suitability and Zonation</th>
<th>Cassava area (Km2)</th>
<th>% of Kenya land surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>General suitability</td>
<td>103,044</td>
<td>18.1</td>
</tr>
<tr>
<td>Suitable outside protected area</td>
<td>81,312</td>
<td>14.3</td>
</tr>
<tr>
<td>Suitable within Food Crop areas</td>
<td>38,629</td>
<td>6.8</td>
</tr>
<tr>
<td>Suitable within Cash Crop areas</td>
<td>2,141</td>
<td>0.4</td>
</tr>
<tr>
<td>Suitable outside food and cash crops areas</td>
<td>38,754</td>
<td>6.8</td>
</tr>
<tr>
<td>Suitable within cultivated lands</td>
<td>40,762</td>
<td>7.2</td>
</tr>
<tr>
<td>Suitable within Non-cultivated areas</td>
<td>38,754</td>
<td>6.8</td>
</tr>
<tr>
<td>Suitable outside Wildlife Conflict areas</td>
<td>67,139</td>
<td>11.8</td>
</tr>
<tr>
<td>Suitable outside Wetland areas</td>
<td>66,092</td>
<td>11.6</td>
</tr>
<tr>
<td>Suitable outside Animal movement paths (3km)</td>
<td>63,953</td>
<td>11.2</td>
</tr>
</tbody>
</table>
Figure 11 General suitability map of cassava
Figure 12 Cassava suitability map with overall zonation

Agronomic Conditions:
1. Mean annual rainfall of 580-1500 mm
2. Mean annual temperature of 16-30 degrees C
3. Altitude of 0-1500 m above sea-level
4. Sandy and well-drained soils
5. Slope less than 45%
3.3 Biodiesel Feedstocks Types and Zoning

3.3.1 *Jatropha curcas*

*Jatropha* is a multipurpose bush plant belonging to the family of Euphorbiaceae. It is a plant with many attributes, multiple uses and considerable potential. It is a native of tropical America, but now thrives in many parts of the tropics and sub-tropics in Africa/Asia.

**Plant characteristics**

It is an undomesticated non-food wild-species that can bear seeds of variable size and oil content for up to 40 – 50 years. Once established, the plant, originating in Central America, can endure drought as it stores nutrients and water in its stem, attracting pests and diseases at this time. The seeds usually contain between 27-40% oil that can be processed to produce a high-quality biodiesel fuel, usable in a standard diesel engine.

**Growth Characteristics**

- **Altitude:** 0 to 1500m
- **Rainfall:** 600 to 1100 mm rainfall per annum
- **Jatropha** grows well under warm and humid climate. Day temperatures between 25-29°C are most suitable for growth of *Jatropha*. Very low temperature less than 15°C affect the growth of plants. Fruit setting is badly affected under hot and dry temperature of above 40°C or below 10°C. Very cold areas do not suit *Jatropha*.
- **Soil:** loamy sand and sandy loam soils. Sandy loam of light soil is ideal for jatropha productivity with adequate rainfall. Optimum soil pH is 6.0 – 7.0.

During the first 6-12 months *Jatropha curcas* growth and future productivity is sensitive to available water, maximum and minimum day/night temperatures, humidity, adequate nutrients, and the right soil for the specific rainfall conditions. While there has been much hype that it will grow in more arid and higher altitude areas, there are so far no indications of any consistent economical yields from most existing genotypes. Seasonal and annual fluctuations in these factors can create widely variable productivity in term of numbers of seeds, seed size and oil content from year to year.

**Crop Husbandry**

Reliability of the seed, and an understanding of the soil, water, nutrient and agronomy, pollinators and pest and diseases needed to create commercially sustainable volumes of *Jatropha* seed, is still being researched and developed. These are now under intensive investigation since most initial growth rates and yields have been significantly lower than initially projected. It is known that jatropha can be established from tissue culture, seed, seedlings, and cuttings. Plants from seeds develop a taproot and four lateral roots, whereas it has been reported that cuttings do not develop a tap root (Openshaw, 2000). For commercial productivity, there is usually only a two month planting window in the warm season before or at the onset of the rains. In the former case, watering of the plants is required until the rains set in. Given Kenya’s predominantly bi-modal rainfall pattern, this is the only way to give *Jatropha* 5 months of continuous adequate water for proper first year establishment. *Jatropha* responds well to organic fertilizer application with some additional N, P, K in the early stages of development. Other nutrients, especially S and Fe, are needed for fruit development and oil synthesis. Depending on the intercropping, harvesting techniques, and environmental factors, recommended spacing of *Jatropha* can vary from 3m x 3m, 4 x 3m to 4x1.5 or 6x2m (double rows). In hand-harvested plantations, investors can experiment with more randomized ‘clumping’ of trees with up to 60% soil cover leaving gaps, intercropping or natural vegetation stands in-between. This naturally prevents the spread of pests and diseases and provides adequate high level pollination of the currently fewer female flowers. *Jatropha* tends to flower at the onset of the rains with fruit developing within three months. Seeds are best harvested from the trees when yellow brown and aired dried to a water content of less than 6%. This usually means a two-three month harvesting period.
Pruning before the rains is an essential operation for jatropha cultivation in order to provide sufficient sunlight, enhance the number of shoots and provide a compact umbrella shape. Results of the previous 3 years of experiment in jatropha plantations indicate that pruning at different heights can be done from first year of planting. An ideal number of 60 to 80 new shoots should be maintained for increasing yield and to facilitate proper flowering.

**Pest and Diseases**

Many pests and diseases have been observed on Jatropha in Kenya, including. Mealy bugs, flea beetles, thrips, mites, termites and web moths are common. Powdery mildew, leaf spots, and root rot have also been observed in some trials. Another beetle *Gyponychus cervinus*, has been observed in Kilifi, though no clear damage symptoms are associated with it so far. Commercial importance of the pest under in jatropha plantation is still under investigation in Kenya. Some natural enemies including spiders, ladybugs and several unidentified parasitoids have been observed (Nabiswa, 2010).

Adequate bee and fly pollination is key to maximizing production with a recommended two beehives per acre. As discussed above, this also means establishment of a variety of indigenous tree stands within the plantation to host natural pest predators, as intensive insecticide and pesticide spraying will also kill the necessary pollinators, resulting in very poor yields.

**Utilization**

The plant can be used to prevent and/or control erosion, to reclaim land, grown as a live fence, especially to contain or exclude farm animals and be planted as a commercial crop. It is not browsed, for its leaves and stems are toxic to animals, but after treatment, the seeds or seed cake could be used as an animal feed (Openshaw, 2000). Various parts of the plant are of medicinal value, its bark contains tannin, the flowers attract bees and thus the plant has a honey production potential; its wood and fruit can be used for numerous purposes including fuel. Of particular importance, the fruit of jatropha contain viscous oil that can be used for soap making, in the cosmetics industry and as a diesel/kerosene substitute or extender. The products from the fruit the exocarp (coat), shell and processed seed cake are rich in nitrogen, phosphorous and potassium (NPK) and/or can be used as soil improvers.

**Intercropping**

Though not much information is available locally, intercropping beans and other legumes is being explored. In other countries reports have shown that groundnuts, patchouli, vetiver, pulses etc could be grown as good intercrop for jatropha, or planting in double rows 6 metres apart to allow beef and dairy cattle to graze between.

**Biofuel Potentials**

For several technical and economic reasons, the full potential of jatropha is far from being realized. The agronomy and management is poorly documented and there is little experience in marketing its products. Thus, frequently, growers do not achieve the optimum output of products, such as the fruit that would bring the greatest rewards. Neither do they have much information about the most lucrative markets. It can currently add great value as an integrated additional source of energy and income to small-holder farming systems, or in small scale plantings on marginal lands where farmers are not dependent on it and can make use of it on a low management ‘pick as available and own use basis’. Other challenges with Jatropha are the toxicity of its seedcake which needs treatment to be available for animal feed, high nitrogen intake, susceptibility to many pest and diseases when stressed, and suitable mechanical harvesting techniques for large scale production.

**Environmental Suitability and Agro-Environmental Zoning for Jatropha**

The suitability mapping is based on Jatropha grown under natural conditions and does not include irrigated
areas. Based on the environmental suitability (average rainfall, temperature and soils), Jatropha suitability areas are concentrated in the Coast, East and West Kenya (Fig. 14) covering an area of about 221,937 km² which is about 39% of the total Kenya surface area (Table 8). These areas also reduce considerably when other factors are considered. For example, removing the protected areas out of the general suitability reduces the land available for jatropha cultivation to 177,700 km² which is 31.2% of the total Kenya surface area (Table 8, Appendix 2). When other areas such as wildlife conflict areas, wetland areas, important bird areas, slopes more than 45% and animal movement paths are zoned out, the area available for jatropha cultivation reduces to 149,302 km² or 26.2% of the total Kenya surface area (Table 8, Fig. 15).

The study has shown that almost the entire available land for jatropha also lies within food and cash crop areas, as well as arable land, whether cultivated or not cultivated (Table 8 and Appendix 2). Taking the productivity factor into consideration, the areas available for Jatropha cultivation were further categorized into productivity levels as low, moderately and highly suitable. The result showed that some areas of Western Kenya and the Coastal strip can be classified as highly suitable, while the whole of eastern Kenya is moderately suitable (Fig. 16). Small trials on the ground suggest that, even within these highly suitable areas’ success is very site specific.

Table 8 Jatropha suitability

<table>
<thead>
<tr>
<th>Suitability and Zonation</th>
<th>Jatropha curcas area (Km²)</th>
<th>% of Kenya land surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>General suitability</td>
<td>221,937</td>
<td>39.0</td>
</tr>
<tr>
<td>Suitable outside protected area</td>
<td>177,700</td>
<td>31.2</td>
</tr>
<tr>
<td>Suitable within Food Crop areas</td>
<td>58,184</td>
<td>10.2</td>
</tr>
<tr>
<td>Suitable within Cash Crop areas</td>
<td>3,835</td>
<td>0.7</td>
</tr>
<tr>
<td>Suitable outside food and cash crops areas</td>
<td>115,340</td>
<td>20.3</td>
</tr>
<tr>
<td>Suitable within cultivated lands</td>
<td>62,017</td>
<td>10.9</td>
</tr>
<tr>
<td>Suitable within Non-cultivated areas</td>
<td>115,340</td>
<td>20.3</td>
</tr>
<tr>
<td>Suitable outside Wildlife Conflict areas</td>
<td>153,811</td>
<td>27.0</td>
</tr>
<tr>
<td>Suitable outside Wetland areas</td>
<td>153,651</td>
<td>27.0</td>
</tr>
<tr>
<td>Suitable outside Animal movement paths (3km)</td>
<td>149,302</td>
<td>26.2</td>
</tr>
</tbody>
</table>
Agronomic Conditions:
1. Mean annual rainfall of 480-2380 mm
2. Mean annual temperature of 18-28.5 degrees C
3. Altitude of 0-1650 m above sea-level
4. Well-drained soils and non-swampy areas

Figure 14 General suitability map of Jatropha
Figure 15 Jatropha suitability map with overall zonation
Figure 16 Jatropha suitability levels
3.3.2 Croton megalocarpus

*Croton megalocarpus* is indigenous to East Africa, and has been widely grown in its mountainous regions as an ornamental for generations. It is believed that the center of its endemism is the Aberdare Mountains of Kenya. It is therefore almost inconceivable that an ecological catastrophe could be triggered.

**Plant characteristics**

*C. megalocarpus* is a pioneer species and it is found growing in cleared parts of natural forests, forest margins or as a canopy tree. After pollination by insects, fruit development takes 5 months and mature fruits can be collected from the ground. In Kenya, seeds mature during October-November in central regions, and from January to March in western regions. *C. megalocarpus* is monoecious, occasionally dioecious.

**Growth conditions**

Its range is the semi-arid and subhumid highlands, at altitudes between 1200 and 2450m with optimum range of 1200-1600 metres, an annual rainfall of 800 to 1900 mm plus optimum range of 100-1400mm; average annual temperatures varying between 11 and 26°C and optimum range of 16-22°C.

**Crop husbandry**

Direct sowing is a viable propagation method. Seeds are extracted by cracking the shell with a hammer or stone, then they are sun-dried to 5-9% mc. Pre-sowing treatment is not necessary. Under ideal conditions, the seeds germinate within 35-45 days, with an expected germination rate of 95% for mature and healthy seed lots. Vegetative propagation can be done by grafting or cuttings. When mature, the tree has relatively open-architecture, that is, a significant amount of sunlight penetrates the canopy to reach the ground. Other crops can in principle be grown under the trees in a two-tiered agroforestry system. Indeed, we have seen maize, a crop with a requirement for relatively high solar intensities, growing beneath *Croton megalocarpus*. The tree grows and produces well at rainfall accumulations of 800 mm/year without need for irrigation.

**Intercropping**

Intercropping croton with maize and legumes such as been is recommended. Because it has deep tap roots croton has limited completion with crops the long tap roots help access sufficient soil nutrients making them available to crops through litter fall. Indeed, it is believed that the trees will augment the soil, in that root exudates will enrich the soil with minerals, and leaf litter with organic carbon.

**Pest and diseases**

The tree is reported to have been damaged by Ambrosia beetles in areas between 1300 to 2100 m in Kenya. Other insect pests recorded include Scolytidae.

**Utilization**

At the end of the trees’ productive life, approximately 50 years from planting, they will be felled; the timber is usable for furniture production, and thus continues to store carbon temporarily. Trees start to seed after four years, producing up to 25kg of seed per tree. Trees of this species are found in forests and often on farms, where they play a major role as boundary markers, windbreaks, shade trees and fuelwood producers. The seeds have 30% of highly unsaturated oils suitable for biodiesel. As the seeds contain 50% protein, the cake is a highly nutritious poultry feed. *Croton macrostachyus* seeds have 19% oil.

**Biofuel potentials**

The potential of croton for biofuel is already being exploited in Kenya. *Croton* trees are planted as windbreaks in Kenya and their use as a source of biofuel may benefit rural economies there. As arable land is under population pressure, people have been cutting down the windbreaks to expand farmland. This new use may save the windbreaks, which in turn should help fight desertification. Unlike the other feedstocks discussed
above, *Croton megalocarpus* simply drops its seedpods when they become ripe, over the course of just a few weeks. These can be caught in inverted “umbrellas,” or more simply raked together and picked up.

**Environmental Suitability and Agro-Environmental Zoning for Croton**

The suitability mapping is based only on croton growing in its natural habitat. Based on the environmental suitability (average rainfall, temperature and soils) the natural distribution range of croton is mainly in Central and Western Kenya (Fig. 18). The total suitable area is 62,773km2 which is about 11% of the total Kenya surface area (Table 5). When the protected areas area removed out of the general suitability the land available for croton cultivation is 46,266km2 which is 8.1% of the total Kenya surface area (Table 9, Appendix 2). When other important areas such as wildlife conflict areas, wetland areas, important bird areas, slopes more than 45% and animal movement paths area zoned out the total land available for growing croton 35,254km2 or 6.2% of the total Kenya surface area (Table 9, Fig. 19). In Central region and part of Western region (e.g. Kisii, Bomet, Kericho), the areas suitable for croton growing lie within the same range as cash crops such as coffee and tea. On the other hand the entire land suitable for croton growing lies within areas classified as arable land whether cultivated or uncultivated (Table 9 and Appendix 2). Based on crop productivity, the study also attempted to categorize the suitable areas into varying suitability levels as low, moderate and high (Fig. 20). Highly suitable areas are found mainly in the central and western highlands.

![Figure 17 Croton tree, seed and biodiesel](image)

**Table 9 Croton suitability**

<table>
<thead>
<tr>
<th>Suitability and Zonation</th>
<th>Croton megalocarpus area (Km2)</th>
<th>% of Kenya land surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>General suitability</td>
<td>62,773</td>
<td>11.0</td>
</tr>
<tr>
<td>Suitable outside protected area</td>
<td>46,266</td>
<td>8.1</td>
</tr>
<tr>
<td>Suitable within Food Crop areas</td>
<td>32,842</td>
<td>5.8</td>
</tr>
<tr>
<td>Suitable within Cash Crop areas</td>
<td>4,415</td>
<td>0.8</td>
</tr>
<tr>
<td>Suitable outside food and cash crops areas</td>
<td>8,654</td>
<td>1.5</td>
</tr>
<tr>
<td>Suitable within cultivated lands</td>
<td>37,611</td>
<td>6.6</td>
</tr>
<tr>
<td>Suitable within Non-cultivated areas</td>
<td>8,654</td>
<td>1.5</td>
</tr>
<tr>
<td>Suitable outside Wildlife Conflict areas</td>
<td>35,950</td>
<td>6.3</td>
</tr>
<tr>
<td>Suitable outside Wetland areas</td>
<td>35,734</td>
<td>6.3</td>
</tr>
<tr>
<td>Suitable outside Animal movement paths (3km)</td>
<td>35,254</td>
<td>6.2</td>
</tr>
</tbody>
</table>
Agronomic Conditions:
1. Mean annual rainfall of 800-1900 mm
2. Mean annual temperature of 11-26 degrees C
3. Altitude of 1200-2450 m above sea-level
4. Light deep and well drained soils

Figure 18 General suitability map of croton
Figure 19 Suitability map of croton with overall zonation
Figure 20 Suitability levels of croton
3.3.3 Canola (Rapeseed)
Scientific name: *Brassica napus* (rapeseed) *Brassica campestris* (canola).

Rapeseed or canola is a member of the cabbage family (Brassicas or Crucifers). This family also contains plants, such as, mustard, turnips, and kale and most importantly crambe or Abyssinian Mustard (*Crambe abyssinica*). It grows well in regions that have colder climatic conditions. The edible oil variety of rapeseed is called canola. Commercial varieties of rapeseed were introduced from Europe, Australia and Canada (KCWORP, 1983). Breeding and selection activities of rapeseed have been done in Njoro with 14 varieties being released to wheat and barley farmers (NPBRC, 2000). The Kenya Genetic Resources Center has collected 18 land races of rapeseed mainly from Rift Valley. Since the rapeseed varieties in Kenya have low erucic acid and glucosinolates they are considered to be canola (NPBRC, 2000).

**Plant characteristics**
Canola grows to a height of 0.75 to 1 m. It has four distinct stages of development. At the seedling stage the crop can easily be suppressed by weeds. Increasing leaf area occurs at the rosette stage until the crop reaches the budding stage. Yellow flowers start forming at the top of the stem at the flowering stage. Flowering lasts two to three weeks after the initial flower appears. Pod filling occurs 5 to 7 weeks after flower initiation.

**Growth conditions**
- Maturity period: 2½-5 months
- Temperature range: 10-30°C
- Altitude: 1830-2740m
- Rainfall: 1000-2000mm. Canola requires more rain during its vegetative stage and some rain during its flower and pod fill stages.
- Soil types: Medium textured and well drained soil. Canola is tolerant to low soil pH (pH 5.5) and saline conditions.

**Utilization**
Canola has edible oil. Rapeseed was introduced in Kenya by wheat farmers to enrich their soil quality. Rapeseed does this by protecting the soil from erosion, suppressing weed growth and improving soil structure through its extensive root system.

**Crop husbandry**
The seed rate for rapeseed varies from 8 to 12 kg/ha depending on the adjustment of the planting equipment. The critical stage for canola is its seedling stage. Weeds can easily suppress its growth at this stage so they should be controlled. After this stage, canola suppresses weeds on its own - due to an increase in the leaf area. When 30-40% of the pods have turned yellow the crop is considered ready for harvest. After this stage, shattering of the pods leads to heavy seed loss hence the need to manage the crop at harvest time (Weiss, 1983).

**Pests and diseases**
As a member of the cabbage family, canola is susceptible to diamondback moth, army worm, aphids and harlequin bugs. Diseases such as alternaria, black spot, black leg, white rust, white leaf spot and downy mildew have been reported in Kenya (KCWORP, 1983). So far introduction of rapeseed varieties resistant to black leg has not succeeded because black leg disease in Kenya is virulent (KCWORP, 1983).
Intercropping
Maximum land equivalent ratio (1.75) and benefit cost ratio (4.17) was observed in intercropping canola with sunflower (Akam et al., 2007). The study concluded that intercropping of canola with sunflower in comparison with sole conventional sown sunflower crop at 75 cm inter row space enhanced the per unit income by about 21.9 percent. The intercropping also increased the per unit income by about 34 percent over sole conventional canola crop.

Uses
Canola leaves are edible and considered a delicacy in Asia. The oil from rapeseed was used to lubricate steam engines and as a biodiesel feedstock in Europe. It is also used in the manufacturer of soaps. Due to the decreased erucic acid level in canola, the oil is less bitter and edible. Canola oil is used as salad oil and in the manufacture of margarines and shortenings. The oil seed meal or cake is used as livestock protein feed supplement (Nagaraj, 1995).

Biofuel potential
Field operations (crop husbandry) of canola are mechanized; this makes rapeseed an easy candidate for biofuel. 46% of the seed is oil that can be extracted then used as a lubricant in its neat form and when processed it can be used as biodiesel which has a longer shelf life than the oil.

Environmental Suitability and Agro-Environmental Zoning for Canola
Based on the environmental suitability (average rainfall, temperature and soils) the suitable area for canola growing is limited to Western Kenya (Fig. 22) covering an area of about 23,763 km2 or about 4.2% of the total Kenya surface area (Table 10). Removing the protected areas area from the general suitability, the land available for canola cultivation is about 13,935km2 which is about 2.4% of the total Kenya surface area (Table 10, Appendix 2). When other important areas such as wildlife conflict areas, wetland areas, important bird areas, slopes more than 45% and animal movement paths area zoned out the total land available for growing canola is about 11,242km2 or 2.0% of the total Kenya surface area (Table 10, Fig. 23). The area suitable for rapeseed cultivation coincide with areas of both food and cash crop areas such as wheat and maize. The entire rapeseed area lies within arable land cultivated or uncultivated (Table 10 and Appendix 2).

Table 10 Canola suitability

<table>
<thead>
<tr>
<th>Suitability and Zonation</th>
<th>Canola (Rapeseed) area (Km2)</th>
<th>% of Kenya land surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>General suitability</td>
<td>23,763</td>
<td>4.2</td>
</tr>
<tr>
<td>Suitable outside protected area</td>
<td>13,935</td>
<td>2.4</td>
</tr>
<tr>
<td>Suitable within Food Crop areas</td>
<td>10,834</td>
<td>1.9</td>
</tr>
<tr>
<td>Suitable within Cash Crop areas</td>
<td>1,742</td>
<td>0.3</td>
</tr>
<tr>
<td>Suitable outside food and cash crops areas</td>
<td>947</td>
<td>0.2</td>
</tr>
<tr>
<td>Suitable within cultivated lands</td>
<td>12,988</td>
<td>2.3</td>
</tr>
<tr>
<td>Suitable within Non-cultivated areas</td>
<td>947</td>
<td>0.2</td>
</tr>
<tr>
<td>Suitable outside Wildlife Conflict areas</td>
<td>11,602</td>
<td>2.0</td>
</tr>
<tr>
<td>Suitable outside Wetland areas</td>
<td>11,396</td>
<td>2.0</td>
</tr>
<tr>
<td>Suitable outside Animal movement paths (3km)</td>
<td>11,242</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Figure 22 General suitability of canola

Agronomic Conditions:
1. Mean annual rainfall of 1000-2000 mm
2. Mean annual temperature of 10-30 degrees C
3. Altitude of 1830-2700 m above sea-level
4. All types of drained and saline soils
**Rapeseed (Canola) Suitability and Overall Zonation**

Agronomic Conditions:
1. Mean annual rainfall of 1000-2000 mm
2. Mean annual temperature of 10-30 degrees C
3. Altitude of 1830-2700 m above sea-level
4. All types of drained and saline soils
5. Slope less than 45%

---

*Figure 23 Suitability of canola with overall zonation*
3.3.4 Castor
Scientific name: *Ricinus communis*
Castor is an oil seed crop that grows wild across East Africa. Annual and perennial forms of castor are found in neglected spaces, roadsides and untended gardens (Acland, 1971). Perennial varieties of castor are relatively drought tolerant because of their deep tap roots. KARI stations in Njoro and Katumani have carried out research on castor over the years (Menin, 2006 and Njeru-Ngare et al, 2010). Investigations done in Njoro have recommended four castor varieties for commercial production of castor (Njeru-Ngare et al, 2010). Forty five accessions of castor have been collected from Eastern, Western and Rift Valley provinces.

**Plant characteristics**
Perennial and annual castor varieties are found in Kenya, and depending on the variety they can grow to 0.9m to 6m. The inflorescent of castor is made of a panicle with female flowers at the top and male flowers at the bottom. After pollination, each female flower produces a thick walled spiny capsule with three loculi. Cross pollination occurs to a high degree in castor because female flowers open long before male flowers.

**Growth conditions**
- Maturity period: 5-10 months
- Temperature range: 15-39°C, frost can severely affect castor
- Altitude: 0-2000m above sea level
- Rainfall: 400-2000 mm mean annual rainfall. Castor varieties have less extensive root systems hence they require reliable rainfall during establishment. The crop also seeds poorly when wet conditions coincide with flowering.
- Soil types: well drained deep soils - castor is sensitive to water logging. The tap root of the perennial variety of castor extends to a great depth.

**Crop husbandry**

**For perennial castor varieties**
Perennial castor varieties are left to grow wild, so it is mostly self-seeded. It is sometimes semi-cultivated as a windbreak, along boundaries and terrace banks, at a spacing of about 2m by 2m. The crop usually sprouts after it has been broken by strong winds or animals. Perennial castor varieties' capsules shatter easily so most of the seed is collected from the ground. Since it needs little attention, perennial castor is well suited for a small cash income with minimum input. The yields are yet to be established.

**For biennial castor varieties**
Biennial varieties of castor have not been reported as found in Kenya. They have been found in other parts of the world but are not being improved for commercialization. Annual forms of castor are being bred for industrialization (Baldanzi et al, 2003).

**For annual castor varieties**
The time for sowing should allow for unlikely wet weather in the second half of the crop’s life. The seedbed should be kept free of weeds since the young saplings are delicate and mechanical removal of weeds is highly inadvisable in the early stages of crop growth. A spacing of 0.3m by 0.9m is mostly used for annual varieties because they tend to be shorter than perennial varieties. Since annual castor varieties have non shattering capsules, they can be picked from the plant when they are mature.

**Pest and disease control**
Sucking pests do the most damage to castor because they cause die-back of the inflorence and growing
points. Grasshoppers and larvae feed on the leaves, thus affecting the overall crop performance. Castor is noted as one of the crops that is highly susceptible to pests, so fortnightly sprays are recommended from flowering to harvesting. Diseases seldom seriously damage castor; however leaf spots caused by *Alternaria* and *Ceropora ricinella*, and rust caused by *Melampsora orcinii*, affect the photosynthetic area.

**Intercropping**

Intercropping of castor and legumes can provide substantial yield advantages compared to sole cropping.

**Utilization**

Castor oil was traditionally used to cure hides and for cosmetic purposes. Because it contains ricinoleic acid, castor can be used in many industrial products e.g. hydraulic fluids, jet engine lubricants, plastics, synthetic textiles, soap and paint.

**Biofuel potential**

Yields of castor range from 0.23 to 1.2 tonnes/ha/year depending on whether it is rain-fed or irrigated (Menin, 2006). In order to get a high yield, irrigation of castor must not be done using sprinklers because the flowers can easily drop off. About 40-55% of the seed is made of oil. The viscosity of castor oil needs to be adjusted for it to be used in engines. Castor can provide oil to lubricate moving parts in machinery. Shorter dwarf varieties have the advantage over *Jatropha* of being more easily mechanically harvested in the first seed harvest. The main fatty acid in its seeds is ricinoleic acid which is highly poisonous, but which is soluble in alcohol (unlike other biodiesels), reducing the energy input for trans-esterification. However the oil is highly viscous, which leads to some experts saying it is not suitable as straight vegetable oil or biodiesel, except maybe in a small percentage as a blend. It maintains its viscosity at high temperatures. Due to its many other industrial uses, castor oil fetches a much higher price than most other biodiesel oils. The toxicity of the remaining cake may cause difficulties in manual handling. Non ricin varieties are being researched.

**Environmental Suitability and Agro-Environmental Zoning for Castor**

Castor is the second most widely spread plant in terms of suitability, after sweet sorghum. Based on the environmental suitability (average rainfall, temperature and soils) the natural distribution range of castor spreads from Western, Rift Valley, Central, Eastern to Coastal region covering an area of 240,494km² or 42.2% of the country (Fig. 25, Table 11). When the protected areas are removed out of the general suitability the land available for castor cultivation, the area reduces to 192,303km² which is 33.8% of the total Kenya surface area (Table 11, Appendix 2). On excluding other important areas such as wildlife conflict areas, wetland areas, important bird areas, slopes more than 45% and animal movement paths area zoned out the total land available for castor cultivation is 159,115km² or 28.0% of the total Kenya surface area (Table 10, Fig. 26). Castor, being widely spread in its suitability like sweet sorghum, means that a large chunk of the available land is taken by national parks and game reserves such as Tsavo, Maasai Mara, Samburu, Meru and others. While castor is less in competition with cash crops in terms of the area of coverage (Table 11, Appendix 2), it is all found in arable lands whether cultivated or uncultivated (Appendix 2). Based on crop productivity, the study also attempted to categorize the suitable areas into varying suitability levels as low, moderate and high (Fig. 27). The highly suitable areas are scattered in agriculturally marginal to medium potential areas.
Table 11 Castor suitability

<table>
<thead>
<tr>
<th>Suitability and Zonation</th>
<th>Castor area (Km²)</th>
<th>% of Kenya land surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>General suitability</td>
<td>240,494</td>
<td>42.2</td>
</tr>
<tr>
<td>Suitable outside protected area</td>
<td>192,303</td>
<td>33.8</td>
</tr>
<tr>
<td>Suitable within Food Crop areas</td>
<td>65,324</td>
<td>11.5</td>
</tr>
<tr>
<td>Suitable within Cash Crop areas</td>
<td>5,377</td>
<td>0.9</td>
</tr>
<tr>
<td>Suitable outside food and cash crops areas</td>
<td>121,236</td>
<td>21.3</td>
</tr>
<tr>
<td>Suitable within cultivated lands</td>
<td>70,854</td>
<td>12.4</td>
</tr>
<tr>
<td>Suitable within Non-cultivated areas</td>
<td>121,236</td>
<td>21.3</td>
</tr>
<tr>
<td>Suitable outside Wildlife Conflict areas</td>
<td>166,047</td>
<td>29.2</td>
</tr>
<tr>
<td>Suitable outside Wetland areas</td>
<td>163,603</td>
<td>28.7</td>
</tr>
<tr>
<td>Suitable outside Animal movement paths (3km)</td>
<td>159,115</td>
<td>28.0</td>
</tr>
</tbody>
</table>
Figure 25 General suitability map of castor
Figure 26 Castor suitability map with overall zonation
Figure 27: Suitability levels of castor

Agronomic Conditions:
1. Mean annual rainfall of 400-2000 mm, with optimum of 750-1000 mm
2. Mean annual temperature of 15-39 degrees C, with optimum of 20-30 degrees C
3. Altitude of 0-2000 m above sea level, with optimum of 300-1800 metres
4. Well-drained soils and non-swampy areas
5. Slope less than 45%
3.3.5 Cotton
Scientific name: *Gossypium* spp
Kiswahili name: *Pamba*

Cotton is one of the most important sources of income for smallholders in many of the semi-arid regions of Africa. However, profitability for small producers is often marginal due to average yields that are well below the potential of varieties grown under rain fed conditions. In Southern and Eastern Africa average yields range from 400-750 kg/ha of seed cotton, while those in research plots often average 3,000 kg/ha and above. Cotton yields are low mainly due to poor quality planting seeds, poor and untimely land preparation, inadequate pest control measures. Because of the low production and high vulnerability to decreased prices, cotton farmers are easily persuaded to avoid cotton growing (Kariuki et al., 2008). Lint was considered the most valuable product of the cotton plant, so a number of breeding programs concentrated on this aspect of cotton. However, after the world economic meltdown that was caused in part by a spike in fuel prices more attention is being given to using oil in the cotton seed for biofuel production. About 278 land races of cotton have been collected in Coast, Central, Eastern, Rift Valley and Western provinces of Kenya. The Kenya Agricultural Research Institute (KARI) and Cotton Development Authority (CDA) have been actively involved in the improvement of cotton in Kenya.

**Plant characteristics**

Cotton is a perennial crop with regular flowering cycles depending on climatic conditions. It exhibits dimorphic branching with the lower stems producing vegetative branches and the upper branches producing reproductive branches. Most of its roots are found in the top 30cm in non-alluvial soils but they can penetrate deeper in alluvial soils. Tap root development is impeded by the presence of a hardpan or murram layer in the soil. But under favorable conditions it can grow up to 4.5m deep.

**Growth conditions**

- **Maturity period:** The crop reaches maturity five months from planting and thereafter exhibits regular flowering patterns (one or two crop harvests can be done in a year depending on the rainfall distribution pattern of the area).
- **Temperature range:** 20-30°C
- **Rainfall:** 600-1300mm
- **Altitude:** 0-1400m above sea level
- **Soil types:** Cotton tolerates a wide range of soils from acidic sands (pH 5) to alkaline clays (pH 8), provided they are well drained.

**Crop husbandry**

Initial planting of the crop should be done by fitting crop water requirements to the available moisture: i.e. more rain should occur at flowering time, which reaches its peak 1½ months after the initial flower appears. Plant spacing is based on the specific variety, with recommended distance between the rows being 0.9m and that between the hills varying from 0.3 to 0.45m. Thinning of the crop is done when the saplings are 10-15cm high. Cotton responds well to fertilizer but since Kenyan soils were until recently considered fertile with potassium, past fertilizer recommendations did not consider this. However with increased intensity of cultivation this nutrient may become deficient. Since cotton grows slowly, regular weeding needs to be done. With good husbandry and efficient pest control, cotton seed (i.e. lint and seed) yields can be as high as 3400 kg/ha, but an average yield under farm conditions ranges from 220 -1600 kg/ha. Cotton harvesting is done by picking (either by hand or use of machinery) of cotton bolls. These are then taken to the ginnery where seed is separated from lint. Ginning percentages in Kenya range from 32-37%: this implies seed yields range from 63-68%.
Pests and disease control
Insecticidal dust and sprays have been recommended to control cotton’s worst pest: insects. However, the use of integrated pest management reduces production costs for farmers (Kariuki et al., 2008). Nematodes impede root development, while larvae (bollworms) of a number of moths cause severe vegetative destruction. The worst is caused by the American bollworm (H. armigera). In dry areas of Kenya, cotton is attacked by strainers (Dysdercus spp) which introduce fungus that stains cotton as they suck water out of seeds in the cotton boll. Major cotton diseases include bacterial blight, Fusarium wilt and Verticilium wilt. Bacterial blight is controlled by a combination of seed dressing and breeding for tolerance.

Intercropping
Farmers can intercrop cotton with mungbean, cowpea, peanut or soybean. With this technology, farmers can produce cotton and protein-rich legumes at the same time in the same field. Intercropping cotton with mungbean, cowpea, peanut or soybean has several advantages. The scheme does not reduce seedcotton yield. Instead it increases income per unit area because two crops are planted at the same time. Moreover, legumes also enrich soil fertility. Because no crop is displaced, the scheme can be included easily into the existing rotational cropping pattern.

Utilization
Although lint was considered the most valuable product of cotton, the oil from the seed has been used in the manufacture of cooking oil, margarine and soap. Cotton seed cake is a nutritious high protein animal feed. Linters are used in carpet and upholstery manufacture. In Kenya, cotton is currently grown solely by small-scale farmers in Western, Nyanza, Central, Rift Valley, Eastern and Coast Provinces of Kenya. Most of the cotton is grown on holdings of less than one hectare by an estimated 200,000 farmers. Cotton in the country is mainly grown in arid and semi arid areas where there are limited economic activities. Cotton yields averaged 572 kg/ha of seed cotton or 191 kg/ha of lint which is 23% of the potential yield in the year 2006 (Kariuki et al., 2008) (Table 12).

Table 12 Cotton production by province 2001-2003; 2006

<table>
<thead>
<tr>
<th>Area planted (ha)</th>
<th>Western</th>
<th>Nyanza</th>
<th>Rift Valley</th>
<th>Central</th>
<th>Eastern</th>
<th>Coast</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>2,035</td>
<td>6,724</td>
<td>991</td>
<td>300</td>
<td>10,370</td>
<td>4,010</td>
<td>24,430</td>
</tr>
<tr>
<td>2002</td>
<td>543</td>
<td>5,850</td>
<td>894</td>
<td>362</td>
<td>9,054</td>
<td>3,460</td>
<td>20,171</td>
</tr>
<tr>
<td>2003</td>
<td>1,957</td>
<td>5,724</td>
<td>244</td>
<td>310</td>
<td>14,058</td>
<td>2,762</td>
<td>24,955</td>
</tr>
<tr>
<td>2006</td>
<td>7,000</td>
<td>7,300</td>
<td>635</td>
<td>430</td>
<td>15,900</td>
<td>5,012</td>
<td>36,277</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production (bales)</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western</td>
<td>1,400</td>
<td>585</td>
<td>1,460</td>
</tr>
<tr>
<td>Nyanza</td>
<td>3,860</td>
<td>19,16</td>
<td>3,860</td>
</tr>
<tr>
<td>Rift Valley</td>
<td>1,083</td>
<td>448</td>
<td>233</td>
</tr>
<tr>
<td>Central</td>
<td>150</td>
<td>16</td>
<td>205</td>
</tr>
<tr>
<td>Eastern</td>
<td>8,272</td>
<td>6,324</td>
<td>8,393</td>
</tr>
<tr>
<td>Coast</td>
<td>4,549</td>
<td>3,319</td>
<td>3,625</td>
</tr>
<tr>
<td>Total</td>
<td>19,314</td>
<td>12,808</td>
<td>17,776</td>
</tr>
</tbody>
</table>

Source: Export Processing Zones Authority 2002.

Biofuel potential
The Kenya government policy ‘Vision 2030’ has identified cotton as one of the crops that would alleviate poverty. The introduction of a biofuel industry in Kenya will make cotton an attractive crop to farmers because they will now get two useful products from the plant: lint and seed. Cotton production in Kenya has suffered because of low yields and pest infestations (Kariuki et al., 2008).
Environmental Suitability and Agro-Environmental Zoning for Cotton

Based on the environmental suitability (average rainfall, temperature and soils), the suitable areas for growing cotton are mainly on the upper parts of Coast, in Malinda, lower Tana River and Lamu. It is also spread in small pockets in eastern, Rift Valley and Western Kenya, an area covering 41,390km² or 7.3% of the country (Fig. 29, Table 13). When the protected areas are removed out of the general suitability the land available for cotton cultivation is 33,760km² which is 5.9% of the total Kenya surface area (Table 13). By excluding other important areas such as wildlife conflict areas, wetland areas, important bird areas, slopes more than 45% and animal movement paths the total land available for cotton growing is 24,053 km² or 4.2% of the total Kenya surface area (Table 13, Fig. 30). Cotton poses minimum competition to cash crops; however the whole area is within arable land whether cultivated or uncultivated (Table 13 and Appendix 2).

Table 13 Cotton suitability

<table>
<thead>
<tr>
<th>Suitability and Zonation</th>
<th>Cotton area (Km²)</th>
<th>% of Kenya land surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>General suitability</td>
<td>41,390</td>
<td>7.3</td>
</tr>
<tr>
<td>Suitable outside protected area</td>
<td>33,760</td>
<td>5.9</td>
</tr>
<tr>
<td>Suitable within Food Crop areas</td>
<td>6,114</td>
<td>1.1</td>
</tr>
<tr>
<td>Suitable within Cash Crop areas</td>
<td>490</td>
<td>0.1</td>
</tr>
<tr>
<td>Suitable outside food and cash crops areas</td>
<td>27,156</td>
<td>4.8</td>
</tr>
<tr>
<td>Suitable within cultivated lands</td>
<td>6,603</td>
<td>1.2</td>
</tr>
<tr>
<td>Suitable within Non-cultivated areas</td>
<td>27,156</td>
<td>4.8</td>
</tr>
<tr>
<td>Suitable outside Wildlife Conflict areas</td>
<td>26,899</td>
<td>4.7</td>
</tr>
<tr>
<td>Suitable outside Wetland areas</td>
<td>25,282</td>
<td>4.4</td>
</tr>
<tr>
<td>Suitable outside Animal movement paths (3km)</td>
<td>24,053</td>
<td>4.2</td>
</tr>
</tbody>
</table>
Figure 29 General suitability map of cotton

Agronomic Conditions:
1. Mean annual rainfall of 600-1300 mm
2. Mean annual temperature of 20-30 degrees C
3. Altitude of 0-1500 m above sea-level
4. Black cotton soils
Figure 30 Suitability map of cotton with overall zonation
3.3.6 Sunflower
Scientific name: *Helianthus annuus*
Sunflower was introduced in Kenya as a potential oil crop. Due to their deep tap roots, sunflowers tend to be drought tolerant (Acland, 1971). Since Kenya has diverse agro-ecological zones, the breeding of sunflower to suit different zones has been done by KARI. Early to late maturing varieties that take 100 to 140 days to reach maturity after planting have been developed at the KARI Njoro Station of (Mathu et al., 2007). Some have been released to the market by the Ministry of Agriculture. The Kenya Plant Genetic Resource Centre has collected 18 local land races of sunflower from Eastern and Rift Valley Provinces.

**Plant characteristics**
Sunflower is an annual crop that grows 0.6 m to 4.5m high depending on the variety. It has a strong tap root with a dense surface mat of feeding roots. The flowers are about 30cm in diameter with yellow petals forming an outer ring.

**Growth conditions**
- Maturity period: 3-6 months
- Temperature range: 20-28°C
- Altitude: 0-2600m above sea level
- Rainfall: 500-1200 mm
- Soil types: Well drained loam soils

**Crop husbandry**
The time for planting sunflower in any region should allow for enough rain at flowering so that the crop can mature during a dry spell. This timing is critical because it also ensures a good harvest. The land should be ploughed then harrowed to ensure a fine seed bed. When wheel traction causes soil compaction on the rows during other field operations, this has significant effect on the generative and vegetative growth of the plant (Bayhan et al., 2002). Hence the need to adjust tractor tyre spacing to ensure that wheel pressure occurs between the rows. Inter-row spacing is recommended at 75cm while intra-row spacing is recommended at 30cm. The crop should be weeded at regular intervals until it is 90cm high. Thereafter the weeds are suppressed by shading. When the soil is drawn up around the stems during weeding, this discourages lodging.

**Pest and diseases**
Birds are the main pests that can cause 100% loss of the crop. This can be mitigated by planting vast areas of the crop without trees in the neighborhood. Scarecrows, bird chasers and noise are effective tools against birds. Insect pests also attack sunflower. The most common disease incidences that affect sunflower include Stem and Head rot, Yellow Blotch Virus, Grey Mold, Brown (leaf) rust, Charcoal rot, White blister rust and Downy mildew.

**Utilization**
Edible oil and animal feed formulations are the main products of sunflower. Since sunflower has good drying properties that do not affect colour, it is used to make some paints and vanishes for a niche market. The seeds can also be eaten as a snack.

**Biofuel potential**
Sunflower has potential for biodiesel use in Kenya, as it will grow across a wide altitude and temperature range, can grow in lower rainfall areas, takes 5 – 10 months to mature, and has a reasonable yield. However, its oil is also high grade edible oil and the cake is used for animal feed.
Intercropping sunflower
Since sunflower does not provide good ground cover, intercropping legumes with sunflower has been experimented on in other countries (Kandel et al., 1997). A good intercropping combination should increase total production per unit area as compared to a pure crop. Several researchers have reported on studies intercropping sunflower with legumes. Putnam (1986) reported that sunflower is a crop well adapted to intercropping. Zekeng (1980) studied strip-intercropping soybean (Glycine max (L.) Merr.) and dry edible bean (Phaseolus vulgaris L.) in sunflower at Fargo, North Dakota. She reported intercropping did not significantly influence the yield of the sunflower but reduced yields of both soybean and edible beans.

Environmental Suitability and Agro-Environmental Zoning for Sunflower
Based on the environmental suitability (average rainfall, temperature and soils) the suitable areas for growing sunflower spreads mainly from southern, coast, east and parts of western Kenya, an area of 140,003 km² or 24.6% of the country (Fig. 32, Table 14). When the protected areas are removed from the general suitability, the land available for sunflower cultivation is 104,574km² which is 18.4% of the total Kenya surface area (Table 14) - a big portion of which is taken by Tsavo National Park. On excluding other important areas such as wildlife conflict areas, wetland areas, important bird areas, slopes more than 45% and animal movement paths, the total land available for sunflower growing is 86,414km² or 15.2% of the total Kenya surface area (Table 14, Fig. 33). Except for parts of coast, upper eastern around Mt. Kenya and small pockets of western regions, sunflower does not compete significantly with the current grown cash crops; however the whole suitable areas lie with arable both cultivated and uncultivated (Table 14 and Appendix 2).

<table>
<thead>
<tr>
<th>Suitability and Zonation</th>
<th>Sunflower area (Km²)</th>
<th>% of Kenya land surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>General suitability</td>
<td>140,003</td>
<td>24.6</td>
</tr>
<tr>
<td>Suitable outside protected area</td>
<td>104,574</td>
<td>18.4</td>
</tr>
<tr>
<td>Suitable within Food Crop areas</td>
<td>43,246</td>
<td>7.6</td>
</tr>
<tr>
<td>Suitable within Cash Crop areas</td>
<td>1,950</td>
<td>0.3</td>
</tr>
<tr>
<td>Suitable outside food and cash crops areas</td>
<td>63,462</td>
<td>11.1</td>
</tr>
<tr>
<td>Suitable within cultivated lands</td>
<td>45,231</td>
<td>7.9</td>
</tr>
<tr>
<td>Suitable within Non-cultivated areas</td>
<td>63,462</td>
<td>11.1</td>
</tr>
<tr>
<td>Suitable outside Wildlife Conflict areas</td>
<td>90,289</td>
<td>15.9</td>
</tr>
<tr>
<td>Suitable outside Wetland areas</td>
<td>88,986</td>
<td>15.6</td>
</tr>
<tr>
<td>Suitable outside Animal movement paths (3km)</td>
<td>86,414</td>
<td>15.2</td>
</tr>
</tbody>
</table>
Figure 32 General suitability map of sunflower

Agronomic Conditions: 
1. Mean annual rainfall of 600-1200 mm 
2. Mean annual temperature of 20-28 degrees C 
3. Altitude of 0-2600 m above sea-level 
4. Well drained and loam soils

Legend:
- District boundary
- Lakes
- Suitable areas

0 70 140 210 Kilometers
Sunflower Suitability and Overall Zonation

Agronomic Conditions:
1. Mean annual rainfall of 500-1200 mm
2. Mean annual temperature of 20-28 degrees C
3. Altitude of 0-2600 m above sea-level
4. Well-drained and loam soils
5. Slope less than 45%

Figure 33: Suitability map of sunflower with overall zonation
3.3.7 Coconut palm
Scientific name: *Cocos nucifera*
Coconut palm is grown in nearly 90 countries along the tropical belts. In Kenya, the most important palm tree is *Cocos nucifera*. The tree grows naturally at sea level in light sandy soils. It originated in the Pacific from where it has now spread throughout the tropics in hot humid coastal areas. In Kenya, it is mainly planted at the coast, and in a few inland areas as ornamental.

**Plant characteristics**
Coconut is a large palm, growing to 30 m tall, with pinnate leaves 4–6 m long, and pinnae 60–90 cm long; old leaves break away cleanly, leaving the trunk smooth. The term coconut can refer to the entire coconut palm, the seed, or the fruit, which is not a botanical nut. Unlike some other plants, the palm tree has neither tap root nor root hairs; but has a fibrous root system. On the same inflorescence, the palm produces both the female and male flowers; thus the palm is monoecious. The coconut palm yields up to 75 fruits per year. Nearly all parts of the palm are useful, and it has significant economic value.

**Growth Conditions**
- Maturity period: 6 to 10 years
- Temperature range 22-27°C
- Altitude: 0-1500m above sea level
- Rainfall: 1000 mm to 2000 mm
- Soil types: sandy soils and is highly tolerant of salinity

**Crop Husbandry**
Propagated through seeds, which are raised in trenches for 4 months before planting out. For better sprouting, treat the seeds by burying the whole fruit in the ground with the tip end up, with about ¼ of the fruit above the surface of the soil. Transplant once germination is achieved and the first leaf is about 15 cm.

**Intercropping**
Growing a number of other crops in association with coconuts is a widespread practice in all coconut-growing areas. The rationale for the practice is that other crops can profitably be grown between or under the coconuts during the different growth stages of the palms and thus the overall productivity of the land under this long-duration crop can substantially be increased.

**Biofuel potential**
Coconut oil can be used as a fuel in one of three ways:
- It can be burned in an unmodified diesel engine, either on its own or blended with diesel. Despite physical and chemical differences between diesel and coconut oil, such as the latter’s higher viscosity, there are reports of pure coconut oil being used in diesel engines without apparent ill effects. However, it is generally considered that the long-term use of fuel blends containing over 20% coconut oil is liable to result in very high maintenance costs due to problems such as sticking of fuel injectors and clogging of filters (Pandey et al 2005, Fürstenwerth 2006).
- It can be burned in a specially-designed or adapted engine. Such engines typically include a device that preheats the fuel to increase its viscosity prior to injection. An alternative is the use of a ‘dual-fuel’ engine, which starts up using diesel; coconut oil can be introduced once the engine has reached a high temperature. The use of specialised engines such as these is a good option for large and medium-sized power generation (Cloin 2007).
- The coconut oil can be converted into ‘biodiesel’, suitable for use in an ordinary diesel engine, by reacting the oil with methanol and a sodium hydroxide catalyst; glycerine is produced as a by-product (Murugesan et al 2009).
Utilization
Coconut palm is a versatile plant from which many products are made including: copra, toddy (mnazi), leaves (makuti), brooms, coconut shell, shell charcoal, baskets, coir fiber, piwa, fresh coconut juice and handcrafts. The coastal people’s economy revolves around the coconut - the “tree of life” - and it has a great significance in terms of food, shelter and employment. Palm wine tapped from unopened spathe of coconut commonly known as “mnazi” or “mdafu” is a unique product, consumed most widely as indigenous beer. Coconut production in Kenya for 2003-2007 is presented below (Table 15):

Table 15 Coconut production in Kenya, 2003-2007

<table>
<thead>
<tr>
<th>Year</th>
<th>Area (Ha)</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production (Tons)</td>
<td>56,937</td>
<td>69,245</td>
<td>61,824</td>
<td>61,117</td>
<td>61,874</td>
<td></td>
</tr>
<tr>
<td>Total Value (Millions Ksh.)</td>
<td>700.3</td>
<td>775.5</td>
<td>692.4</td>
<td>690.6</td>
<td>742.5</td>
<td></td>
</tr>
</tbody>
</table>

Source: Ministry of Agriculture: Economic review of Agriculture 2008

Diseases and Pests
The coconut mite, *Acacia guereronis* Keifer, is known to attack the tree in African continents, (Moraes et al, 2004).

Environmental Suitability and Agro-Environmental Zoning for Coconut
Based on the environmental suitability (average rainfall, temperature and soils) distribution of coconut suitable area is limited to the coastal strip covering and area of 4,489 km2 or 0.8% of the country (Fig. 35, Table 16) making it the smallest feedstock in terms of area coverage. By excluding the protected areas such as Shimba Hills in Kwale, Arabuko-Sokoke in Kilifi and protected Kaya forests, the land available for coconut cultivation is 3,475km2 which is 0.6% of the total Kenya surface area (Table 16). By removing other important areas such as wildlife conflict areas, wetland areas, important bird areas, slopes more than 45% and animal movement paths the total land available for coconut growing is only 1,803km2 or 0.3% of the total Kenya surface area (Table 16, Fig. 36) of which almost all lies with food and cash crop area (Table 16 and Appendix 2); though coconut, being edible, is itself both food and cash crop.

Table 16 Coconut suitability

<table>
<thead>
<tr>
<th>Suitability and Zonation</th>
<th>% of Kenya land surface</th>
<th>Coconut area (Km2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General suitability</td>
<td>4,489</td>
<td>0.8</td>
</tr>
<tr>
<td>Suitable outside protected area</td>
<td>3,475</td>
<td>0.6</td>
</tr>
<tr>
<td>Suitable within Food Crop areas</td>
<td>2,295</td>
<td>0.4</td>
</tr>
<tr>
<td>Suitable within Cash Crop areas</td>
<td>703</td>
<td>0.1</td>
</tr>
<tr>
<td>Suitable outside food and cash crops areas</td>
<td>479</td>
<td>0.1</td>
</tr>
<tr>
<td>Suitable within cultivated lands</td>
<td>2,996</td>
<td>0.5</td>
</tr>
<tr>
<td>Suitable within Non-cultivated areas</td>
<td>479</td>
<td>0.1</td>
</tr>
<tr>
<td>Suitable outside Wildlife Conflict areas</td>
<td>1,926</td>
<td>0.3</td>
</tr>
<tr>
<td>Suitable outside Wetland areas</td>
<td>1,895</td>
<td>0.3</td>
</tr>
<tr>
<td>Suitable outside Animal movement paths (3km)</td>
<td>1,803</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Figure 35 General suitability map of coconut
Figure 36 Suitability map of coconut with overall zonation

Coconut Suitability and Overall Zonation

Agronomic Conditions:
1. Mean annual rainfall of 950-1350 mm
2. Mean annual temperature of 24-35 degrees C
3. Altitude of 0-750 m above sea-level
4. Sandy soils
5. Slope less than 45%

Legend:
- District boundary
- Wetlands
- Lakes
- Suitable areas
- Wildlife movement paths (3 km)
- Protected areas
- Wildlife conflict areas

Figure 36 Suitability map of coconut with overall zonation
3.3.8 Oil Palm
Scientific Name: *Elaeis guineensis*

Oil Palm is naturally growing in many parts of the world including Malaysia, Indonesia and the wetter parts of Africa: principally West Africa. In East Africa, the palm is growing naturally in many parts of Tanzania and in parts of Uganda, but rare in Kenya, except in Western Kenya.

**Plant characteristics**

Palm is the tallest monocot in the world, reaching heights of 60 meters. The trunk will develop an auxiliary bud at a leaf node, usually near the base, from which a new shoot emerges. The new shoot, in turn, produces an auxiliary bud and a clustering habit results. They have large evergreen leaves that are either palmately ('fan-leaved') or pinnately ('feather-leaved') compound and spirally arranged at the top of the stem. The inflorescence is a panicle or spike surrounded by one or more bracts or spathes that become woody at maturity.

**Growth Conditions**

The oil palm needs an even temperature range of 24 – 28°C to produce well and its cultivation is limited to regions between 10 degrees North and 10 degrees south latitudes and areas below 500 m altitude. The plant needs plenty of sunshine and an annual mean rainfall of between 1500 mm and 3000 mm. It can tolerate a dry period of about 3 months without an appreciable decrease in yield. Soil should be well drained and fertile. Brief and occasional flooding does not cause any damage. The optimal soil pH range is 5.5 – 7.

**Crop Husbandry**

Palm trees are “unisexual” in that they have male and female flowers within the tree. The tree can be propagated through seed and through wildlings. Seeds are slow to germinate with germination complete in only 3-6 months. Termite feeding on the fallen fruits can accelerate germination. Proper selection of mother trees will enhance production. The seeds, once germinated, can be grown in tubes or baskets in the nursery for one year, before planting in the field. Dig pits of 60 cm x 60 cm x 60 cm and space widely at 8-9m between palms to give the crowns of the trees enough space to produce large quantities of fruits. Oil palm plantations composed of specially selected and cloned varieties of palm trees start to produce fruit after four to five years and reach maturity and the highest rate of productivity when the trees are 20 to 30 years old. The fruit bunches each weighing between 15 and 25 kg are made up of between 1000 and 4000 oval-shaped fruits, measuring some three to 5 cm long. Established palms should be fertilized, with a slow release palm fertilizer, a minimum of twice per year; four applications are better. Avoid pruning trees whenever possible. Most palms shed their fronds naturally, but others drop the fronds after some time.

FAO is now exploring opportunities for boosting production of palm oil in western Kenya through its programme on integrated farming systems. This will involve seedlings from Costa Rica being grown in community nurseries and by the region’s largest sugar producer, Mumias Sugar Company. Their cultivation would allow small-scale and industrial producers to reduce the edible oil deficit and, in the process, provide a badly needed source of extra income for western Kenya’s rural areas, where half of the population lives in poverty.

**Intercropping**

Growing a number of other crops in association with palm is a widespread practice in all palm-growing areas. The rationale for the practice is that other crops can profitably be grown between or under the palms during the different growth stages of the trees and thus the overall productivity of the land under this long-duration crop can substantially be increased.

**Biofuel potential**

Palm oil can be used as biofuel at a blend of 2 to 5% processed liquid palm oil with 95 to 98% petroleum
diesel or biodiesel as methyl esters of palm oil. Processed liquid palm oil i.e. liquid fraction of refined palm oil with low FFA (<0.1%) and dirt was successfully evaluated as fuel for electricity generator and diesel vehicles.

Utilization
Kenya’s vegetable oil sub-sector is currently based on a total of 11 oil products imported for either domestic consumption or for export, with priority being given to Palm oil, coconut oil and corn oil (Farm Concern International, 2008). Oil palm is the highest yielding oil crop in the world, given that one tree yields between 35-50kg of oil in a year. Oil palm produces red palm oil that is rich in vitamins. Palm oil gets its characteristic red hue from the carotene that is present in the palm fruit. The palm fruit is the source of both palm oil (extracted from palm fruit) and palm kernel oil (extracted from the fruit seeds). Palm oil is one of the few vegetable oils relatively high in saturated fats (like coconut oil) and thus semi-solid at room temperature. Palm oil is the second most traded vegetable oil crop in the world, after soy. Over 90% of the world’s palm oil exports are produced in Malaysia and Indonesia.

The key players in the vegetable oil industry dealing with palm oil in Kenya comprise refiners who convert crude oils into a form suitable for their target market consumption and processors who further add value to the refined oils for various uses.

Table 17 Palm oil Imports to Kenya for 2007

<table>
<thead>
<tr>
<th>Region</th>
<th>Quantity (Tones)</th>
<th>Value (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Africa</td>
<td>2,014</td>
<td>1,816,233</td>
</tr>
<tr>
<td>Europe</td>
<td>306</td>
<td>358,664</td>
</tr>
<tr>
<td>Far East</td>
<td>412,104</td>
<td>298,503,738</td>
</tr>
<tr>
<td>India</td>
<td>1,490</td>
<td>1,099,714</td>
</tr>
<tr>
<td>Middle East</td>
<td>1</td>
<td>1,057</td>
</tr>
<tr>
<td>Rest Of Africa</td>
<td>55</td>
<td>84,085</td>
</tr>
<tr>
<td>Grand</td>
<td>415,970</td>
<td>301,863,490</td>
</tr>
</tbody>
</table>

Source: CBIK, EPC, 2008

Palm oil imports to Kenya have been relatively on the increase over the last decade due to high demand for palm oil and diversity of use by the processors.

Figure 37 Palm oil imports to Kenya (1998 – 2007)
Environmental Suitability and Agro-Environmental Zoning for Palm Oil

Based on the environmental suitability (average rainfall, temperature and soils) general suitable areas for palm oil are limited to coastal strip, western Kenya and pockets of eastern Kenya covering an area of 12,204 km$^2$ or 2.1% of the country (Fig. 39, Table 17). Excluding the protected areas from the general suitability, the land available for palm oil cultivation is about 11,555 km$^2$ which is 2.0% of the total Kenya surface area (Table 17). On excluding other important areas such as wildlife conflict areas, wetland areas, important bird areas, slopes more than 45% and animal movement paths the total land available for palm oil growing is about 9,333 km$^2$ or 1.6% of the total Kenya surface area (Table 17, Fig. 40) of which is almost entirely food and cash crop area (Appendix 2) though palm oil being edible is itself both food and cash crop.

Table 18 Palm Oil suitability

<table>
<thead>
<tr>
<th>Suitability and Zonation</th>
<th>Oil Palm area (Km$^2$)</th>
<th>% of Kenya land surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>General suitability</td>
<td>12,204</td>
<td>2.1</td>
</tr>
<tr>
<td>Suitable outside protected area</td>
<td>11,555</td>
<td>2.0</td>
</tr>
<tr>
<td>Suitable within Food Crop areas</td>
<td>10,012</td>
<td>1.8</td>
</tr>
<tr>
<td>Suitable within Cash Crop areas</td>
<td>859</td>
<td>0.2</td>
</tr>
<tr>
<td>Suitable outside food and cash crops areas</td>
<td>734</td>
<td>0.1</td>
</tr>
<tr>
<td>Suitable within cultivated lands</td>
<td>9,981</td>
<td>1.8</td>
</tr>
<tr>
<td>Suitable within Non-cultivated areas</td>
<td>734</td>
<td>0.1</td>
</tr>
<tr>
<td>Suitable outside Wildlife Conflict areas</td>
<td>9,722</td>
<td>1.7</td>
</tr>
<tr>
<td>Suitable outside Wetland areas</td>
<td>9,421</td>
<td>1.7</td>
</tr>
<tr>
<td>Suitable outside Animal movement paths (3km)</td>
<td>9,333</td>
<td>1.6</td>
</tr>
</tbody>
</table>
Figure 39 General suitability map of palm oil
Figure 40 Suitability of palm oil with overall zonation

Agronomic Conditions:
1. Mean annual rainfall of 1000-2000 mm
2. Mean annual temperature of 22-27 degrees C
3. Altitude of 0-1500 m above sea-level
4. Well-drained soils and pH < 7.5
5. Slope less than 45%
3.3.9 Crambe
Scientific name: *Crambe abyssinica*

The Mediterranean region is crambe’s center of origin. Crambe is also prevalent across Asia and Western Europe. Crambe is an oil crop from the mustard family. The seed contains 30 to 35 percent oil with 40 to 60 percent erucic acid in the oil. The erucic acid oil content of crambe is 8-9 percent more than that of rapeseed. Crambe and rapeseed are high erucic acid (HEA) oils. These HEA oils have long hydrocarbon chains (22-carbons) and an isolated double bond. These structures give HEA oils their characteristic trait of having high fire and smoke points (282.2°C).

**Plant Characteristics**

Crambe is a cool-season crop adapted to the Great Plains. It takes 90 to 100 days to reach maturity from the date of planting. Plant height ranges from 28 to 53 inches, but can vary depending on planting time, the season and plant density. Crambe is an indeterminate flowering plant. The crambe flowering period lasts two to three weeks. Its small white four-petaled flowers are on a panicled raceme. The seed pods are a buff to dirty white color. The first pods will usually remain on the plant until the last pods mature. Delayed harvest, and hard rains or hail near maturation can increase shattering. Crambe has small seed (27,000 seeds/lb), and its bushel weight is between 22 and 25 lbs/bushel. It takes between 90 and 95 days from the date of sowing to physiological maturity.

**Growth Conditions**

- It adapts well in fertile ground, good drained with pH from 6.0 to 7.5
- Crambe is a culture to be planted as a winter crop (Tropical) or spring crop in some regions (subtropical).
- Temperature: It is important there is a control day and night temperature. This can variate in the day temperature from 18°C to 30°C and Night temperature range from 10°C to 23°C . The ideal would be maximal a difference of 10 degrees Celsius e.g. around 28°C – 18°C day, or 23°C and night 19°C. It requires soil temperature of 10°C degrees.
- Rainfall: Crambe is resistant to drought. The critical period is the germination phase that demands a moist soil. It does not tolerate rainy periods or humid ground. Therefore it has to be planted at the end of the rain season and requires 20 mm per months rainfall for germination in the first month and 40 mm monthly rainfall for the next 60 days. It becomes more tolerate to humidity after the first month. However it needs about 30mm to 40 mm monthly in the next 60 days.
- Soil: It is susceptive to soil acidity or high Al +3 levels, therefore is recommended for well balanced soil new neutral pH (6.0 – 7.5) allowing the root to grow deep thus improving drought tolerance.

**Crop Husbandry**

A firm, well-packed seedbed is essential for the successful establishment of crambe. Proper seedling requires a depth of less than 1 inch and good seed-soil contact. Crambe needs a seedbed that is free of debris and weeds, firm, and well-packed. After disking, a final harrowing or rolling with a culti-packer should create a smooth and firm planting surface. The final tillage operation should be done less than a week before planting to kill weed seedlings. Conventional tillage practices are effective in creating a proper seedbed.

Planting depth is critical for good stands. Seeding depths should not exceed 1 inch. Preferred planting depths are from 1/2 to 3/4 inch deep in a well prepared seedbed. Small grain drills will do an excellent job in placing the seed at the proper depth. When using a grain drill with disk openers, the disks should be set to run at the soil surface. Hoe drills can place seed in moist soil when there is a dry surface layer. In hoe drilled fields, heavy rains can bury the slow growing seedlings. Seeding rates vary with row spacing. Row widths of 12-15cm usually have highest yields. Where the field has weed problem wide rows 50cm allows mechanical inter-row cultivation. If the crop is planted in wide rows the crop tends to be 10cm taller and could be prone to fall over before harvest. Burry the seed to 1.25cm - 2.0cm depth. Rolling the ground after planting...
increases seed to soil contact, decreases clod size and improves emergence. In Europe the stocking rate is 150 plants/m² to achieve a good yield and suppress weeds. You can also sow at a rate 200 to 250 viable seeds/m² if weather conditions are not good. If planting on wide rows you could reduce seed rate by 20%.

Crambe will benefit from a proper fertilization program. Soil testing is the most effective way to monitor a fertility program. Suitable levels of nitrogen (N) and phosphorus (P) are essential for rapid stand establishment and high yields.

**Intercropping with crops**

Crambe can be rotated with rice, soya, maize and sugarcane. This has shown to increases crop yields by 0.1-3t/ha. Rotation also has an added advantage of suppressing weeds, pests and diseases. It can be used as a cover crop in the dry season to suppress weeds, generate additional income and protect soil from erosion. Crambe does not compete with food crops.

Crambe is a cover crop that produces additional income over the total cropping cycle and reduces pesticide input costs during the main crop production period. Most growers in Brazil practice conservation farming, or minimum tillage. Crambe helps this system: It is planted immediately after the soya harvest and suppresses late emerging weeds that grow on the residual moisture after the summer rainy period. The crop is harvested early and provides time to prepare the land for the subsequent summer crop. The residual vegetation contains material that discourages grazing and inhibits parasitic soil micro-organisms, root knot nematodes in soya. Crambe is a nurse crop that will become a biofuel because it supports food crops rather than competing with them.

**Pest and Diseases**

Few crambe disease problems have been reported primarily due to a lack of commercial acreage. A lack of disease reports does not indicate that disease problems will remain small. As acreage expands, opportunities for diseases will increase greatly. *Sclerotinia sclerotiorum* (white mold or stem rot) has been reported in some fields in USA. White mold survives in the soil in its dormant stage, called sclerotia. Infections can start in the branches, leaves, pods and stems. High plant populations, high humidity, high inoculums levels and excessive nitrogen levels create conditions suitable for white mold. Effective control measures include rotating to non-host crops, deep plowing and use of certified seed free of sclerotia. Avoid rotations with sunflower and drybean, due to their white mold susceptibility.

*Alternaria brassicae* (black spot) is a devastating disease of rapeseed, canola and the other cole crops in the United States and Canada. Crambe is very susceptible to black spot. Black spot overwinters on plant debris and seed. All above-ground plant parts are susceptible to infection by spores produced on plant debris or infected plants. Control methods include use of disease-free certified seed, use of a long-term rotation and control of weedy mustards and volunteer crambe and canola.

As with all new introductions, care must be taken when in introducing Crambe in Kenya and full assessment done on its invasive potentials as well as pest and diseases.

**Utilization**

HEA oil has several uses and is widely used industries. When converted to erucamide it is a slip agent in plastics manufacturing. Erucamide keeps individual plastic sheets from sticking together. The plastics industry uses more than 20 million pounds of HEA oil as slip agents. The mining industry is researching HEA oil as a potential flotation agent in separating mined aggregate. Steel casting industries use a few ounces of crambe oil per ton of steel as a high temperature (2,500°F) lubricant. Crambe oil is useful in the textile and steel industries for spinning lubricants and sheet steel fabrication. The Agricultural Research Service (ARS) at Peoria, Illinois used crambe oil to develop Nylon 1313 in the 1970s. Uses of this nylon include temperature and moisture resistant products, such as brake lines, tubing and gears.
Biofuel potentials
HEA oil’s abilities to withstand high temperatures and remain liquid at low temperatures make HEA oil good lubricating and transfer oil. Oil content is 26 to 38% (Italian varieties 38%) which is fit for industrial oil and biodiesel. Crambe can be burnt as a biomass fuel, an alternative to firewood.

Environmental Suitability and Agro-Environmental Zoning for Crambe
Based on the environmental suitability (average rainfall, temperature and soils) general suitable areas for crambe are mainly in coastal areas, parts of central and south eastern, and western Kenya covering an area of 25,839 km2 or 4.5% of the country (Fig. 42, Table 19). Excluding the protected areas from the general suitability, the land available for palm oil cultivation is about 22,685 km2 which is 4.0% of the total Kenya surface area (Table 19). On excluding other important areas such as wildlife conflict areas, wetland areas, important bird areas, slopes more than 45% and animal movement paths the total land available for crambe growing is about 15,908 km2 or 2.8% of the total Kenya surface area (Table 19, Fig. 43) of which is almost entirely food and cash crop area (Appendix 2). Suffice to mention that the since there is still no experience of crambe growing in the country, data used to extrapolate the growing areas pure based on experience from other countries.

Table 19 Crambe Suitability

<table>
<thead>
<tr>
<th>Suitability and Zonation</th>
<th>Crambe area (Km2)</th>
<th>% of Kenya land surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>General suitability</td>
<td>25,839</td>
<td>4.5</td>
</tr>
<tr>
<td>Suitable outside protected area</td>
<td>22,685</td>
<td>4.0</td>
</tr>
<tr>
<td>Suitable within Food Crop areas</td>
<td>13,628</td>
<td>2.4</td>
</tr>
<tr>
<td>Suitable within Cash Crop areas</td>
<td>2,325</td>
<td>0.4</td>
</tr>
<tr>
<td>Suitable outside food and cash crops areas</td>
<td>6,568</td>
<td>1.2</td>
</tr>
<tr>
<td>Suitable within cultivated lands</td>
<td>16,103</td>
<td>2.8</td>
</tr>
<tr>
<td>Suitable within Non-cultivated areas</td>
<td>6,568</td>
<td>1.2</td>
</tr>
<tr>
<td>Suitable outside Wildlife Conflict areas</td>
<td>16,675</td>
<td>2.9</td>
</tr>
<tr>
<td>Suitable outside Wetland areas</td>
<td>16,135</td>
<td>2.8</td>
</tr>
<tr>
<td>Suitable outside Animal movement paths (3km)</td>
<td>15,908</td>
<td>2.8</td>
</tr>
</tbody>
</table>
Figure 42 General suitability map of crambe
Figure 43 Suitability of Crambe with overall zonation
The results of this suitability mapping exercise have demonstrated that most feedstocks lie within arable land areas whether the land is cultivated or uncultivated. Sweet sorghum and castor are the only feedstock which showed high suitability in agriculturally marginal to moderate zones. The study has demonstrated that Jatropha, for example, is more productive in areas of higher rainfall and less productive in dryer or agriculturally marginal areas and so is unlikely to be promoted commercially in the drylands of Kenya. Unlike previous claims (Opensahw 2000) this study recognises that *Jatropha curcas* for instance, is susceptible to pests and diseases, needs adequate nutrition to be commercially productive, and while it can withstand a period of drought, it needs adequate water to become established, thus potentially competing with food crops. Feedstock production in marginal areas requires heavy investment in terms of irrigation and soil nutrient improvement and genetic improvement to develop high productive drought tolerant feedstock varieties. Though irrigation may not be an option, given water scarcity in the drylands, investing in water harvesting and conservation technologies may help to make rainwater more available. Passed research in dryland forestry has developed a number of water harvesting techniques (Muok et al, 2007) which could be tried for biofuel feedstock production in marginal areas.

The study has shown that coast, central and western regions of Kenya have the highest potential for biofuel feedstock production. These areas are also known to be region of high agricultural potential and biodiversity. The study has demonstrated that areas of high agricultural potentials are also the areas of high potential for biofuel feedstocks production. This finding calls for a careful balancing when deciding where to grow feedstock so that it does not affect food production. This consideration is more critical where the feedstock in question is non-edible and hence not interchangeable. There are several options that could be considered such as planting along boundaries: such is the case of Jatropha in some countries such as India. The feedstock can also be intercropped with food crops where the two are compatible (Singh et al, 2007). Whatever the case, care must be taken to ensure that food production is not compromised, bearing in mind that farmers are rational decision makers who are able to make decisions based on the opportunity cost provided by biofuel feedstocks.

For edible biofuel feedstocks such as sweet sorghum, cassava, sunflower, etc which farmers are already growing on their own for food purposes, the scenario presented could be different depending on how production is planned. For example, it has been repeatedly claimed that planting sweet sorghum will enhance food security. When sweet sorghum is used as biofuel feedstock as the first harvest will be used as food and only after that the ratoon is harvested as a biofuel feedstock. Others such as sunflower, have been cultivated by farmers for years with little impact on food security; problems may arise when large scale planting will use land that was being used to plant food crops.

In terms of the size of suitable area, sweet sorghum has the highest coverage of 263,965 km² (46.4%) followed by castor at 240,494 km² (42.2%) and Jatropha at 221,937 km² (39%). The feedstock with the least area suitability is coconut with 4,489 km² (0.3%) followed by oil palm at 12,204 Km² (2.1%) and canola at 23,763 km² (4.2%). Feedstocks with wider suitability could be more appropriate when considering a national biofuel programme, but this is not to say that the smaller feedstocks in terms of area should be ignored, since different feedstock have their advantages and disadvantages. It can also be expected that indigenous feedstocks such as *Croton megalocarpus* may emerge to have a more extended range than predicted and be less problematic than currently better known crops such as Jatropha. Some new exotic species such as *Crambe abyssinica* have has not been grown in the country before which means that the data used for extrapolating the growing areas were experience from other countries. Such species should first be piloted in controlled environment to refine the ecological requirements, management regimes and carry out assessment of diseases and pest as well as invasive potential.

Producing feedstocks from varied geographical regions allows a combination of feedstocks to be allocated to respective ecological niches thereby enabling exploitation of environments that uniquely support a given feedstock. This supports the hypothesis that a combination of feedstocks is considered to
be more efficient and sustainable. Producing biofuel in varied geographical regions has an added advantage in decentralizing biofuel development into different parts of the country will help to diversify development activities, thus benefiting more communities in the rural areas.

In East Africa, three of the most popular feedstocks now being discussed are jatropha, castor, and palm oil. In some countries such as Ethiopia, biofuel policy is almost entirely based on jatropha, even though many other feedstocks are being planted. For example, in the case of jatropha, because it is a source of non-edible oil suitable for use in large, stationary engines (such as generators, pumps, etc.) as well as conversion to biodiesel, many companies and development agencies have been involved in promoting its planting in various locations in Kenya. While there is nothing wrong with this, there is need for research to go hand in hand to determine claims of toxicity, life cycle studies to include water use balance, crop husbandry, invasiveness, as well as associated pest and diseases. The same can be said of castor. Some reports indicate that though jatropha and castor are generally considered drought tolerant, yet for high productivity they equally need irrigation, fertilizers, herbicides, and mycorrhizal injection in all but the most suitable areas, which are small in Kenya. Though promotion of palm oil in Kenya has just started in Western Kenya, in Tanzania large multinationals companies are already putting large tracks of land to palm oil production for export. These have a potential to affect food security. Another important question that policy makers need to address in an arid, semi-arid country like Kenya with an expanding human population is whether it is correct to promote food crops as biofuel feedstocks at all and finally, what choices in land use assignments have to be done. In the current study, food crops such as cassava, sweet sorghum as well as edible oil crops such as sunflower, canola, coconut, and palm oil have been covered as possible feedstocks. The advantage of the crop based feedstocks is that because they have been planted by farmers over the years, their husbandry are well understood including pest and diseases with much on-going research in the national and international agricultural research centres. The disadvantage is the potential impact on the food security. This brings to focus the need to diversify feedstocks and include indigenous species such as *Croton megalocarpus*. Though little plantation experience including information on crop husbandry is available, croton is an indigenous tree which makes it less likely to be invasive or to have serious pest and diseases.

The great diversity of physical and climatic conditions in Kenya is reflected in a high diversity of plants and animals. The country has some unique and important biodiversity endowments, *most of which are under threat*. While some of the protected areas are well understood and protected under the relevant legislation, important biodiversity conservation areas outside the projected areas do not have equal protection under the law. There has been little or no economic assessment of the local, national and global environmental values of the areas of high biodiversity outside protected areas. With accelerated expansion of agriculture and introduction of biofuels, assessment and conservation of these areas need to be evaluated quickly as a national priority. Furthermore, wildlife conservation is comparatively vulnerable to the effects of other land uses elsewhere, including for biofuels, for example through deforestation due to charcoal burning, pollution or changed water regimes. Wildlife tourism, one of Kenya’s highest employment sectors and income generating activities is highly sensitive to neighbouring land uses, even if they affect only the aesthetic value of the place rather than its biological aspects.

These national parks and reserves are the backbone of Kenya’s tourism, which is the second largest sector of Kenya’s economy accounting for 12% of GDP. Tourism provides multiplier effect in the development of other industries like agriculture, horticulture, transport and communications. Kenya’s wildlife will become increasingly unique and valuable if maintained. Kenya is at a key moment of choice of which direction to take. This decision needs to be taken collectively and consciously and not just allowed to happen through the vested interests. The parks and reserves are also the main sources of water, particularly the water catchment areas of Mt. Kenya, Aberdares, Elgon, Chyulu, Mau forest and Marsabit. A great percent (about 60%) of Kenya’s electricity comes from hydroelectric dams, most of which are situated on the Tana river, which flows from Mt. Kenya and Aberdares National Parks; and in the Turkwell Gorge in Nasalot National Reserve. In addition, geothermal power is generated in Hells’ Gate National Park.
With increased research, step by step development, at the right scale and with proper consideration, biofuels can in particular, benefit rural Kenyans, providing alternative incomes, more sustainable alternatives to wood fuel and drastically reduce indoor air pollution. This study has also pointed out that without proper integrated and coordinated planning, the promotions of a large scale biofuels industry without due consideration to the sustainability factors, has the potential to:

- Increase the pressure on land use with consequent internal population displacement as well as loss of biodiversity.
- Increase social inequity
- Increase the demand and usage of scarce water causing conflict with other human and agricultural needs.
- Increase environmental pollution.
- Increase chemical pollution of water supplies, fisheries and wildlife,
- Increase erosion in water catchments areas, with the potential for dams to dry up and wetlands to silt up
- Damage wetlands through drainage and irrigation ,
- Increase pressure on downstream coral reefs from siltation,
- Introduce invasive species
- Significantly reduce wildlife habitats, as well as seasonal human and wildlife adaptive transmigration routes and pastures.
- Increase wildlife death tolls and human-wildlife conflicts

A core part of the study has been to map out areas to be excluded from large scale biofuel production in order to safeguard social equity and Kenya’s ecosystems. As the results have shown, past mapping for biofuel feedstock either considered only environmental suitability or, where there was an attempt to map out national and internationally important areas, only nationally recognised protected areas were considered. The current study, has gone further in including areas of recognised and irreplaceable high biodiversity value, whether currently legally protected or not, as well as areas of high socio-economic and cultural value. These include wetlands e.g. Tana River Delta, animal movement paths, human-animal conflict areas, sacred forests e.g. Kaya forest, etc. Some of these are explained in details (Appendix 1).
1. As has been noted in the preceding discussion, almost all the feedstocks have best yield in agriculturally high potential arable lands. Only few feedstocks such as castor and sweet sorghum were classified as highly suitable in agriculturally marginal to medium potential areas. Others such as Jatropha are tolerant to drought and therefore, once established, can survive in agriculturally marginal areas. However, without sufficient rainfall and nutrients, general yield and productivity is very low, making these areas unprofitable for investing in non-irrigated feedstock production. Therefore, careful balancing needs to be done between high suitability areas for feedstock production and the overarching need to safeguard food production and water resources.

2. Marginal and degraded areas, where biofuels pose the least competition with food crops may not yield commercial results with most feedstocks unless accompanied by heavy investment in soil fertility improvement, water harvesting and conservation. Research is also needed to develop arid, semi-arid feedstock varieties that are productive in such areas. There is a need for clear policies, including appropriate policy incentives to attract investors to the agriculturally marginal (degraded) areas.

3. All biofuel feedstocks in Kenya can directly benefit from research and improvement programmes. Issues of potential land use change, high water usage and water and air pollution will remain, but these can be addressed through adhering to careful agro-ecological zoning for biofuel production, and best agricultural practices.

4. In view of increased demand for extensive land areas for investing in biofuels, there is need to improve the land administration systems to deal with conflicting claims between different vested interests and the traditional land usages and ownership rights that are emerging under biofuels expansion. There is need to ensure that changes and production practices associated with biofuel production are sustainable. Responsible land allocation, land use change and policy enforcement, will minimize competition over land, and therefore food insecurity and encroachment on protected and communal areas.

5. Whether or not to promote crop based feedstock and/or feedstocks that also yield edible oils, is a point that needs to be carefully addressed. Though not based on any policy guidelines, in Kenya, jatropha, castor and croton have received high priority among development agents, while edible oils such as palm oil, coconut, sunflower, crambe and canola have so far been less considered. This is in contrast to Tanzania, where large scale planting of palm oil for biofuel has been going on. There is a need for a clear policy on this to guide investors on suitable Kenyan feedstock development.

6. A strategic, comprehensive and credible Environmental impact assessment (EIA) that prevents unsuitable production, needs to be undertaken for all biofuel development projects especially those in areas of high biodiversity, wildlife, forest and water conservation. The EIAs conducted must meet international standards such the internationally recognized principles published by IAIA. The CBD and Ramsar Conventions as well as the Round table on Sustainable biofuels (RSB) have both produced guidance on EIAs and these, along with the current NEMA guidelines can provide for environmental and social safeguards in biofuel development.

7. Listed and identified areas of high conservation value, global and national endemic species habitats, biodiversity hotspots, remaining woodland and forest stands, wetlands and key water catchment areas need to be actively excluded for any large scale biofuel expansion. Expansion in such areas needs to be banned, as without these, Kenya’s functioning but fragile ecosystems will not support future development.

8. A development and conservation Master Plan should precede any large scale biofuel development to ensure that both social, economic, conservation and development objectives are taken on board on the same level and scale. Lost biodiversity and endemic habitats which have evolved over decades and centuries are irreplaceable. It is critical that conservation planning precedes development planning, to avoid irreversible biodiversity and habitat losses. It is also important to develop management plans...
and mobilize resources to support any conservation areas set aside, in order to maintain globally threatened species, fragile ecosystems and associated invaluable ecological goods and services. Well-managed conservation areas would in turn provide a healthy environment and safe buffer zones for any future development projects and provide adequate insect pollinators, birdlife and natural pest predators.

9. Since most of the most biodiversity resources are of trans-boundary in nature, the study recommends carrying out a similar study in all eastern Africa countries.
6.0 REFERENCES


EPFL Energy Center (2008). Roundtable on Sustainable Biofuels


http://www.compete-bioafrica.net/events/events2/seminar_india/ppt/Praj-Sweet-Sorghum.pdf


Nabwera A (2010), Agronomy of Jatropha and how to identify suitable areas. Jatropha Conference Nairobi, 22-23 February 2010


7.0 APPENDIX 1

7.1 National Parks, Reserves, Wildlife Dispersal Areas and Conflict Areas

About 8% of the country is designated specifically for wildlife conservation and tourism. This percentage comprises four marine national parks, five national sanctuaries, six marine national reserves, 22 terrestrial national parks and 28 terrestrial national reserves. This is a substantial proportion of the country, but most would consider it fully justified given the economic, biological, cultural and aesthetic values of wildlife, as well as ethical arguments for conserving wildlife for posterity and the significance for tourism, Kenya's major foreign exchange earner. The values listed are enhanced if the land is kept exclusively for wildlife i.e. in more or less natural state, and most countries set aside some land as parks (though few match Kenya's commitment in this regard). These protected habitats are reservoirs of conserved genetic resources that could be used in bio-prospecting for the improvement of crops or for medicines.

Since most national parks and reserves are not complete ecosystems in themselves, the wildlife in them depend seasonally on dispersal areas, either adjacent to the protected area or some distance away along a seasonal migration route or corridor. The need may be for grazing or forage or for access to key water sources in the dry season. Even a park whose animals remain within the limits of boundary may depend on compatible land use outside. For example, Lake Nakuru National Park could be severely degraded by diversion of water for irrigation, by pollution from industries or agrochemicals - or worse, by destruction of the water catchment, the Mau forest.

Whatever the details of the various mechanisms, the consequence is that the present biological and economic value of protected areas, such as Amboseli NP, Masai Mara NR, Nairobi NP, Shaba/Buffalo Springs NRs, Shimba Hills NP, and Lake Nakuru NP, can only be maintained if the land use around them is compatible with wildlife conservation. However, since most of these dispersal areas/corridors do not permit wildlife conservation, and as the land-use situation keeps changing rapidly, human-wildlife conflicts have continued to increase, in spite of efforts by the government to mitigate them and persuade communities to embrace wildlife conservation. As the population continue to grow, the demand for land increases. Almost all the high potential land outside parks and forest reserves is already being cultivated. Many of the remaining areas of forest, which are unprotected or are Trust land forests under county councils, are gradually being cleared for cultivation. Some forest reserves have also been extensively encroached. As prime agricultural land becomes scarce, cultivation of semi-arid, medium potential land is increasing. The best known example is the expansion of wheat into the wildlife dispersal areas of the Maasai Mara National Reserve. The cultivation becomes riskier and prone to high intensity of human-wildlife conflict in the areas nearer to the Reserve. The promise of short-term profits has proved sufficient to induce wheat farmers to lease Maasai grazing land for the purpose. This has even lead to intensification of conflict, since the Maasai pastoralists who have leased out their lands are forced to move towards the Reserve. Further cultivation and expansion of lands around these areas would lead to intensified conflicts and further degrade the wildlife ecosystem. Other factors leading to conflicts include the subdivision of group communal and trust lands into private lands. The prospect of gains from biofuel may intensify encroachment into these valuable ecosystems, with far reaching consequences.

7.2 Wetlands of Kenya

Wetlands according to the Ramsar Convention articles 1.1 and 2.1 are described as ‘areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres’. They are an important ecosystem because their function and attributes help to support human life and biodiversity on the planet. Wetlands have been categorized as both biomes and ecosystems. They are generally distinguished from other water bodies or landforms by the water level and the type of plants that thrive within them. Specifically, wetlands are characterized by having a water table that stands at or near the surface for a long enough season each year to support hydrophytes. Put simply, wetlands are lands made up of hydric soils. Wetlands have also been described as ecotones, providing a transition between dry land and water bodies.

Wetlands are very productive areas, offering a home to many plant and animal species and being a major storehouse for the world’s water, oxygen and carbon dioxide. Almost every country in the world has its
wetlands. Worldwide, at least 570 million hectares are considered wetlands, about one-twentieth of the world's land surface. During the 20th century the world lost half of its wetland and the pace is not slowing down. Most of these fell victim to drainage and conversion to irrigated agriculture, to pollution, or to overexploitation of resources including fish, timber and water.

In Kenya, wetlands cover 14,000 km² (2.5%) of the country's surface area (Ndiritu et al., 2003). Their rich physical and biological resources are exploited for food, water, medicinal plants, fuel wood, material for building and handicrafts. They are also important for tourism due to their unique landscape and rich biodiversity (Crafter et al., 1991). About 80% of these ecosystems are found outside the formal protected areas. Although most of the wetlands in Kenya are in areas of high rainfall, others are in arid and semi-arid areas, which are important for social-economic development and biological conservation as well.

Importance of Wetlands

Wetlands have global value as reservoirs of water and biodiversity. They contribute to the mosaic of ecosystems which maintain global biodiversity. As transitional habitats between land and open water, they form an important bridge between the terrestrial and aquatic ecosystems. They provide ecological and socio-economic benefits. The ecological services include biodiversity conservation and the preservation of genetic, species and ecosystem diversity. The dynamic nature of wetlands leads to fluctuations in their spatial and temporal utilization by various species including arthropods, zooplankton, phytoplankton, aquatic plants, fish, reptiles, mammals and birds. Wetlands also regulate nutrient cycling, flooding regimes and toxicant removal. From a socio-economic perspective they provide multiple services that include food production, fisheries, cultural benefits, recreation, transportation and dry season grazing land. They also attract income through tourism and serve as critical areas for research and education.

In otherwise dry lands, wetlands provide refuge for aquatic and semi-aquatic animals. Because of geological, physical and climatic barriers, dry land wetlands behave like “bio-geographical islands”. This has important implications for biodiversity conservation. The wetlands serve as centres of species endemism and have a relatively high rate of species extinction because of their isolation. The rate of wetland habitat loss, however, is currently much greater than that of known species extinction.

Loss of wetland habitats in arid and semi-arid areas due to drought and human-induced processes of desertification threatens valuable biological biodiversity because of possible species extinction. If the total genetic resource continues to decline at the current rates, the ability of taxa to adapt to changing conditions through genetic diversity will decline accordingly, and populations may not survive (Denny, 1994). This is true of wetlands as well as other ecosystems in dry lands.

Despite their high productivity and provision of many benefits, wetland ecosystems are facing serious threats due to rapid human population growth which has led to increased demand for wetland resources, unsustainable exploitation, and conversion to other uses. Human population pressure, escalating poverty and inadequate awareness and appreciation of important wetland ecological processes and socio-cultural benefits have aggravated the situation. To a great extent, lapses in policy implementation have accelerated encroachment and degradation of wetland ecosystems. Other threats emanate from wetland drainage for agriculture and human settlements; increased siltation; water catchment destruction; invasion by alien plant and animal species; and pollution by waste disposal and agro-chemicals.

The delay by the government in enacting a wetlands policy, and the lack of regulation and guidelines, threaten the survival of these fragile ecosystems.

Conservation issues

In an outlook for 2020, the report ‘Biofuels in Africa’ reveals how pristine wetland areas especially will become victim of large scale biofuel plantations, such as for sugarcane and palm oil. Sugarcane production is water demanding while ethanol production is only feasible and profitable when large plantations are established. These conditions may lead to extension of sugar production in to wetlands and especially floodplains.

Horticultural farmers are increasingly turning to wetlands in dry areas. Small-scale production of fruit, vegetables and supplementary livestock feed are sustainable economic activities. When horticulture attains a commercial scale without due consideration to other water users, this may lead to completion and conflicts.
Inputs of agro-chemicals also increase, and these cause damage to biological diversity. Establishment of horticultural farms has rapidly expanded in Laikipia, Naivasha and Kajiado areas. However water extraction for industrial, urban and irrigation needs may be, or become, unsustainable. Since the demand for water is rapidly expanding in all parts of the country, methods of harvesting rainwater should be developed to supplement withdrawals from surface and underground water sources.

Because of their prime value in water conservation, wetlands form a critical resource base which should be protected in order ensures that water is available to wildlife, livestock and people at present and in the future.

7.3 Biodiversity Conservation

Kenya is particularly noted for hosting a range of important biodiversity hot spots, including rare and/or endemic species, habitats and ecosystems with high endemism. Kenya has a total of about 7,100 plants species and several thousand subspecies and varieties out of which 265 plant species are endemic. There are estimated 304 mammals out of which 8 are endemic, 869 birds of which 9 are endemic, 106 snakes with one being endemic and 97 amphibians of which one is endemic (Sayer et al., 1992). The endemic species are highly prized because they may well be sources of specific genetic constitutions that confer resistance to diseases, pests, and environmental hazards such as drought; and also sources of medicine for otherwise incurable diseases. These species are also preferred by the local populations for their culinary, organoleptic and ethnomedicinal qualities, and therefore hold a key to food security and sustainable development.


Though less mentioned important bird areas (IBAs) are some of the important biodiversity areas key sites for conservation of birds and other biodiversity though some of these areas occur outside the protected areas IBAs have been identified all over the world, using Birdlife International's objective and scientific criteria. IBA sites are selected because they contain:

1. Globally threatened bird species, such as the Aberdare Cisticola found only in the high altitude grassland.
2. Bird species living only in a small area, such as the Clarke's weaver found only in Arabuko-Sokoke Forest and Dakatcha Woodland.
3. Bird species found in a particular biome, such as those that only live in papyrus wetlands.
4. Exceptionally large gatherings, or congregations, of bird species, such as thousands of water birds found in Tana River.

Nature Kenya and National Museums of Kenya have collected information about birds countrywide, identified 60 IBAs, and published the findings as Kenya Important Bird Areas in 1999. The latest trend and status of IBAs were published in 2007 through collaboration of various organizations led by Nature Kenya. The IBA definition process is dynamic, and new sites may be listed as IBA while others may be de-listed as conditions change. Kenya has about 60 IBA locations that have been identified and mapped. IBAs also form part of wider set of sites called Key Biodiversity Areas (KBAs) which are places of international importance for the conservation of endangered birds, plants, mammals, reptiles, amphibians, and other living things. A policy legislation working group coordinated by Nature Kenya is providing policy advice in support of IBA conservation. The IBA concept should be taken up and mainstreamed into routine government planning, conservation action including planning for biofuels production.

7.4 Forests of High Biodiversity Value that lie outside Protected Areas

While most of the forests are governed by the rules and regulations of protected areas, there are a number of forests of high diversity value that are not protected.

Coastal Forests of Kenya

The Coastal Forests of East Africa are a chain of relict forest and thicket patches set within savannah
woodlands, wetlands and agricultural land. The forests extend from Southern Somalia to Southern Mozambique and west to Malawi. They have been defined by WWF as the ‘Eastern Africa Coastal Forests Ecoregion’ and contain two WWF Global 200 ecoregions: the Northern and the Southern Zanzibar-Inhambane Coastal Forest Mosaics.

The Coastal Forests in Kenya are a part of the Northern Zanzibar-Inhambane Coastal Forest Mosaic, which extends from the Kenya-Somali border to the Tanzania-Mozambique border along the coast. The ecoregion includes forest patches found on the islands of Zanzibar, Pemba and Mafia. These forests are characterized by a mosaic of vegetation types including evergreen forest, *Brachystegia* woodland, scrub forest and dry forest. They are typically found in small fragmented patches.

Coastal forests are distinct from the forests of the Eastern Arc in terms of climate, elevation and dominant plant species. Most coastal forests are found at elevations between 0 - 500 m up to a maximum of 1100 m depending on ecological conditions (Burgess et al. 2000).

The biodiversity of the coastal forests is recognized as being of global importance (WWF Global 200, 1998, and Conservation International Global Biodiversity Hotspots, 2004) due to the high levels of biodiversity and endemism found within the small, fragmented and highly threatened patches of forest.

The closed canopy coastal forests retain high numbers of endemic plant and animal species: 554 plant, 5 bird, 3 mammal, 24 reptile, 5 amphibian, 86 mollusc and 75 butterfly. The mosaic of habitats within the Hotspot, including forest, woodland and thicket, contain a greater total number of endemic species: 1750 plant, 11 bird, 11 mammal, 53 reptile, six amphibian and 32 freshwater fish. Of these, there are 533 globally threatened (Red list) species, with 105 species being represented in Kenya and 307 in Tanzania (IUCN 2002). It should be noted that reptiles and fish within the Hotspot are not currently on the IUCN Red list and once included these figures will increase.

This hotspot is also home to a variety of primate species including three endemic and highly threatened monkey species and two endemic species of bush babies. The Tana River, which runs through Central Kenya, is home to two critically threatened and endemic primates, the Tana River red colobus and the Tana River mangabey.

In addition to the high biodiversity values of the coastal forests, they are also important because of their many and varied uses to people. Coastal forests are used as a source of medicinal plants, fuel wood, building materials, food and they help to maintain a regular water supply for towns and villages. They play an important role in reducing soil erosion, maintaining ecological cycles and micro-climates and carbon sequestration.

Many forests have an important cultural value to rural people, such that the forests and people are historically and spiritually bound. For instance the Kaya forests in Kwale and Kilifi Districts in Kenya are sacred to local communities with graves of important elders found within the forest. Sacred forests are also common in Tanzania and Mozambique, where extractive use is closely regulated by communities.

Although the remaining forests scattered throughout the hotspot’s 291,250 km² are typically tiny and fragmented, they contain remarkable levels of biodiversity. These forests also vary greatly in their species composition, particularly among less mobile species; for example, forests that are only 100 kilometers apart may differ in 80 percent of their plant species.

Within the hotspot, the region of highest endemism stretches from northern Kenya to southern Tanzania, possibly also including northernmost Mozambique. Two important subcenters of endemism are also recognized: the Kwale-Usambara subcenter of endemism on the Kenya-Tanzania border, and the Lindi subcenter of endemism in southern Tanzania.

**Conservation Issues**

Despite the obvious importance of the coastal forests in terms of biological value and the high levels of threat by deforestation, only 17% of the Coastal Forest Hotspot is formally protected with just 4% having high levels of protection under IUCN protected area categories I-IV. The two largest protected areas in
Kenya are Arabuko-Sokoke (417 km²) and Shimba (63 km²).

Much of the hotspot’s original forests have been lost to agricultural conversion and urbanization, and only about 10 percent of the original vegetation - 29,125 km² - remains in pristine condition. The remaining habitat is limited to more than 400 patches of lowland forest, covering about 6,259 km². The remaining forest covers about 2 km² along the Jubba River of Somalia, 787 km² in Kenya, 692 km² in Tanzania, and at least 4,778 km² in Mozambique.

The most significant current threat to the Coastal Forests of Eastern Africa Hotspot is the expansion of agriculture. Burning of woody plants for charcoal production causes major habitat loss near coastal towns and alongside main roads. Forests close to tourist areas, such as Arabuko-Sokoke Forest near Malindi and Watamu in Kenya, suffer from the high demand for carving wood (Brachylaena huillensis) and timber for the construction of hotels, private residences and tourist attractions.

The Government has recently given approval to a Canadian-based multinational mining company, Tiomin, Inc., to start mining titanium in the Kwale area. High-grade silica sands for glass manufacture are also mined from deposits in Msambweni, while iron and manganese are mined on a small scale in the Kwale Kaya forests of coastal Kenya.

**Tana River Delta**

Tana River deserves a special mention in this report. The area known as the Tana River Delta is a vast patchwork of palm savanna, seasonally flooded grassland, forest fragments, lakes, marine wetlands and the river itself. This ecosystem supports several communities and enormous numbers of livestock, wildlife and water birds. The people have adapted their lifestyle to seasonal extremes. Farmers cultivate on receding lake edges, seasonally fertile floodplains, and where the river spills fresh water into their fields with the tidal flow. Other people raise livestock or engage in fishing. When the wetlands are left undisturbed, they act like sponges, absorbing floods, storing the water and remaining green during the dry season. The thick vegetation absorbs carbon dioxide gas from the air. In times of drought, pastoralists bring livestock from as far as the Somali and Ethiopian borders to graze on the grasslands. In times of flood, the Delta fills with water, and water birds from all over Kenya nest and raise young, replenishing bird populations throughout the country. Lower Tana River forests have important primate habitats, with two endemic primate subspecies (Tana River red colobus Procolobus (badius) rufomitratus rufomitratus and Tana River mangabey Cercocebus galeritus galeritus), six rare bird species, and near endemic poplar (Populus ilicifolia) (Collar and Stuart, 1988).

The Tana River Delta has been designated an Important Bird Area (IBA), a site critical for the conservation of birds. The Tana Delta qualifies as an IBA under three categories:

a. It shelters birds that are threatened on a world scale: the Southern Banded Snake Eagle, the very local Malindi Pipit, and the migratory Basea Reed Warbler whose breeding grounds in Iraq are also under threat. The Tana River Cisticola, extremely local and on the verge of extinction, has recently been recorded.

b. The Tana Delta is home to a number of birds found only in the East African Coast biome. The moist Palm Savanna that covers part of the Delta is not represented in any protected area in Kenya today.

c. The Tana Delta contains one of the very few and highly important water bird breeding sites in Kenya: over five thousand water birds of at least thirteen species use this site to raise their young. It also provides a habitat for water birds that gather in huge numbers. There are 22 different species of water birds that gather in internationally important numbers in the Delta, including pelicans, herons and storks.

d. Over 1,000 hippos and crocodiles are estimated in the river and associated lakes, there are herds of buffalo, topi, zebra and other wildlife in the palm woodland on the edge of the Delta.

e. The Tana River Red Colobus, one of the world’s most endangered primates, is found in some riverine forest fragments. Marine turtles nest along the beaches, and three different species of true eels have
been recorded from the Tana River. The mangrove forests play an important economic role, sheltering fish and shellfish nurseries that nourish the rich fisheries of Ungwana (Formosa) Bay.

f. The Delta hosts seven plants on the IUCN Red list of threatened species. Three shark species listed under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) have been recorded in the Tana Delta.

g. Three important amphibians include the endemic Tana River caecilian, Boulegerula denhardti and the near-endemic mud-dwelling caecilian Schistometopum gregorii. Reptiles in the Delta include the near-endemic Tana writhing skink Lygosoma tanae and the Ngatana or mabuya-like writhing skink Lygosoma mabuiiformis.

This area is in need of protection, because it is crucial to many animal species like lions, hippos and waterbirds, as well as the livelihoods of local communities. Furthermore, Tana wetlands form a crucial link for many migratory waterbirds on the route to their winter destinations in the South. These birds are coming from Europe, such as the Curlew Sandpiper (Calidris ferruginea) and the little stint (Calidris minuta).

Moreover, thousands of people depend on the Tana wetlands as fishermen or farmers. Herdsmen also require the area for cattle grazing during the dry season. These functions – critical to their livelihoods - will largely disappear if the wetland is converted into a large-scale sugarcane production area.

**Hilltop and Riverine Forests of the Drylands**

Due to severe environmental conditions in the arid and semiarid areas, most of the vegetations are confined to the hilltops and riverine areas. Some hills in the semi arid areas have high elevation that allows for mist formation in the early morning, which support growth of forests. In most time of the year, the hilltop forests are the only vegetation left in the arid and semiarid areas thus becoming a life line for humans living in these areas who depend on the forest for all their basic needs ranging from food, material for shelter, medicine, fuel and other minor products. The hilltop forest also provide dry season grazing for livestock as well as sustaining the biodiversity in these areas. These pockets of forests are vital habitats to long-term maintenance of biodiversity and other processes in the drylands. Some of the hilltop forests have been isolated long enough to form a completely unique ecosystem as well as flora and fauna that are completely different from the lowlands surrounding them.

Due to the pivotal role they play in the survival of the people living around them, the hilltop forests in drylands have been undergoing destruction at unprecedented rate (Gachathi, 1996; Muok et al., 2002). As the forest decline or removed, many forms of plants and animal life that depend on their habitat for survival are invariably lost.

On the hills, precipitation increases with elevation, but temperature and evaporation decrease. This results in relatively cooler and more suitable climate with better developed vegetation of trees, shrubs and lianas on the hilltops, sometimes receiving annual rainfall in excess of 800mm. These restricted hilltops, though geographically within the drylands, are therefore climatically not arid or semi-arid and have mid-altitude forests of the species of the lowlands and of the uplands in addition to those found in the drylands (Gachathi, 1996) (Fig. 5). These unique sites are vital habitats to the long term maintenance of biodiversity and other natural processes in the drylands.

The hilltop forests are of immense antiquity and the species of plants and animals in them have evolved mutual adaptation. On the other hand, the nomads have developed ecological management strategies in harmony with this fragile environment by exploiting different ecological niches. During normal seasons, grazing occurs on the lowland plants; but with the onset of drought, animals gradually move to the hills.

A study was conducted by Kenya Forestry Research Institute in Kajiado District to evaluate importance of the hilltop forests reported the identified the following:

1. Plant medicine use is still common and very popular, and held with a lot of esteem by the pastoralist communities in the drylands.
2. Most plants of use or value to the local community are now found mainly on the hilltop forests.
3. The hilltop forest contains unique relic stands of plants and animals which have become endemic to specific hills as a result of isolation.
4. The higher hills are water catchments, feeding springs vital for the very existence of life in the drylands.
Sugarcane Suitability Outside Protected Areas

Agroecological Conditions:
1. Mean annual rainfall of 1000-1500 mm
2. Mean annual temperature of 10-18 degrees C
3. Altitude of 0-200 m above sea level
4. Level to light slopes
5. Slope less than 45%

Legend:
- District boundary
- Lakes
- Suitable areas
- Protected areas
- Wildlife conflict areas

Sugarcane Suitability Outside Wetlands

Agroecological Conditions:
1. Mean annual rainfall of 1000-1500 mm
2. Mean annual temperature of 10-18 degrees C
3. Altitude of 0-200 m above sea level
4. Level to light slopes
5. Slope less than 45%

Legend:
- District boundary
- Wetlands
- Lakes
- Suitable areas
- Protected areas
- Wildlife conflict areas

Sugarcane Suitability Outside Wildlife Conflict Areas

Agroecological Conditions:
1. Mean annual rainfall of 1000-1500 mm
2. Mean annual temperature of 10-18 degrees C
3. Altitude of 0-200 m above sea level
4. Level to light slopes
5. Slope less than 45%

Legend:
- District boundary
- Lakes
- Suitable areas
- Protected areas
- Wildlife conflict areas

Sugarcane Suitability Outside Wildlife Movement Paths

Agroecological Conditions:
1. Mean annual rainfall of 1000-1500 mm
2. Mean annual temperature of 10-18 degrees C
3. Altitude of 0-200 m above sea level
4. Level to light slopes
5. Slope less than 45%

Legend:
- District boundary
- Wetlands
- Wildlife
- Suitable areas
- Protected areas
- Wildlife conflict areas

Note: The maps illustrate the suitability of sugarcane cultivation outside protected areas, wetlands, wildlife conflict areas, and wildlife movement paths, considering agroecological conditions.
8.0 Appendix 2: Suitability Maps

Crambe Suitability Outside Wildlife Conflict Areas

Agricultural Conditions:
1. Mean annual rainfall of 800-1600 mm
2. Mean annual temperature of 16-30 degrees C
3. Altitude of 500 to 2000 m above sea level
4. Well-drained soil with pH 6.5-7.5
5. Slope less than 45%

Crambe Suitability Outside Wildlife Movement Paths

Agricultural Conditions:
1. Mean annual rainfall of 800-1600 mm
2. Mean annual temperature of 16-30 degrees C
3. Altitude of 500 to 2000 m above sea level
4. Well-drained soil with pH 6.5-7.5
5. Slope less than 45%

Crambe Suitability with Food and Cash Crops

Agricultural Conditions:
1. Mean annual rainfall of 800-1600 mm
2. Mean annual temperature of 16-30 degrees C
3. Altitude of 500 to 2000 m above sea level
4. Well-drained soil with pH 6.5-7.5
5. Slope less than 45%

Crambe Suitability Within Cultivated and Non-Cultivated Areas

Agricultural Conditions:
1. Mean annual rainfall of 800-1600 mm
2. Mean annual temperature of 16-30 degrees C
3. Altitude of 500 to 2000 m above sea level
4. Well-drained soil with pH 6.5-7.5
5. Slope less than 45%