Sustainable Management of Resources in Agriculture

Jatropha Reality Check

A field assessment of the agronomic and economic viability of Jatropha and other oilseed crops in Kenya

gtz Partner for the Future. Worldwide.

commissioned by

Federal Ministry for Economic Cooperation and Development

Published by

Deutsche Gesellschaft für
Technische Zusammenarbeit (GTZ) GmbH

– German Technical Cooperation –

Sustainable Management of Resources in
Agriculture

Dag-Hammarskjöld-Weg 1-5
65760 Eschborn/Germany
T +49 6196 79 2438
F +49 6196 79 802438
E jutta.schmitz@gtz.de
I www.gtz.de

Jatropha Reality Check

A field assessment of the agronomic and economic viability
of Jatropha and other oilseed crops
in Kenya

Study conducted by

ENDELEVU ENERGY

in collaboration with

World Agroforestry Centre
TRANSFORMING LIVES AND LANDSCAPES

KEFRI

Endelevu Energy
World Agroforestry Centre
Kenya Forestry Research Institute

GTZ – Regional Energy Advisory Platform (East Africa)
Nairobi, December 2009

Acknowledgements

The German Technical Cooperation (GTZ) as the sponsor is honored to present this report as the outcome of many months of dedicated research, in such a timely manner. Much of the initial "hype" which set the stage for this assignment has faded away. Increasingly, the skepticism is backed up by critical feedback from practitioners regarding the suitability of Jatropha as a commercial bioenergy crop. At the same time, more considered stakeholders maintain that Jatropha, and other oilseed crops, do hold substantial potentials for sustainable development if applied appropriately, and if sustainability issues are addressed.

This assignment was managed by the GTZ Regional Energy Advisory Platform – East Africa (REAP) on behalf of the GTZ sector project "Sustainable Management of Resources in Agriculture" (formerly "Sustainable Use of Biomass focusing on Bioenergy"), commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ).

The output is among the first systematic attempts at a stock-taking of actual experiences with oilseed feedstocks at a national level in Eastern Africa. We are confident that it will go a long way in allowing stakeholders to distinguish facts from fiction and to argue from an informed point of view. In addition, the study represents an important contribution to the international bioenergy discourse.

We would like to commend the team of consultants and technical experts for their dedicated work, notably Endelevu Energy as the lead consultant, and the World Agroforestry Centre (ICRAF) as well as the Kenya Forestry Research Institute (KEFRI) as the research partners in Kenya. We are particularly grateful for the fact that ICRAF complemented our limited resources with substantial in-house contributions, in particular through the sustained commitment of Ms Miyuki Iiyama, and through Ms Christel Munster.

GTZ also expresses sincere gratitude for all the interviewees among the stakeholders in the country, the district agricultural officers who provided invaluable support, the enumerators for their data collection efforts at times under difficult conditions, and of course the various peer reviews in the country and among the international bioenergy experts.

We hope that this work will enrich the discourse among practitioners, policymakers and academia, and we welcome feedback and comments.

On behalf of GTZ,

Stephan Krall

Programme Manager
Sustainable Management of Resources in Agriculture
German Technical Cooperation (GTZ)

Table of Contents

Charts, Maps and Tables

1. Introduction

German Technical Cooperation (GTZ) has commissioned this study as part of an effort to support informed decision-making by policymakers and private investors. In 2008, the Government of Kenya and GTZ supported a team of experts to prepare a "Roadmap for Biofuels" for Kenya. The Roadmap assessed the theoretical potential of various biofuel feedstocks and made recommendations on how to tap this potential. Following the presentation of these findings, a wide range of stakeholders called for additional empirical information and actual experiences with biofuel feedstocks, and in particular with *Jatropha*. This study attempts to fill this gap through a systematic and comprehensive stocktaking of the experiences and knowledge in Kenya of *Jatropha* and of two other potential oilseed crops, *Castor* and *Croton*.

Fluctuating oil prices and increasing concerns about climate change have led to a global boom of investments and enthusiasm for liquid biofuels over the past few years. In Kenya, much of the excitement has revolved around the shrubby-tree named *Jatropha curcas*, or *Jatropha* for short. Nearly everywhere you turn, someone is promoting this "wonder crop" as the solution to our energy woes. Perhaps even more seductive than claims of energy independence, however, has been the argument that *Jatropha* can alleviate rural poverty and make use of marginal land not suitable for food production.

Reading some news reports, this has seemed like a real win-win situation. Farmers, biofuel producers, consumers, and the environment would all benefit from growing and processing *Jatropha*. According to an article on Time Magazine's website from earlier this year, "renewable energy, it turns out, does grow on trees…unlike corn and other biofuel sources, the *Jatropha* doesn't have to compete with food crops for arable land. Even in the worst of soils, it grows like weeds."[i]

Local papers have also joined in the chorus of praise for this seemingly magical crop, with unverified claims like "*Jatropha* is resistant to drought, pests…" and "[e]xperts say an [sic] hectare of *Jatropha* can produces [sic] 1,900 litres of fuel."[ii] Of course, the so-called "experts" are rarely cited and, even when they are, the basis of their statements is almost never verified. News headlines have continued the parade of stories about *Jatropha's* vast potential: "New Investments to Create 13,000 New Jobs,"[iii] "Tree That Holds Solution to Fuel Crisis and Environmental Conservation,"[iv] and "Boosting Biofuels Without Compromising Food Security."[v]

Various non-governmental organizations and small private sector companies and individuals have further contributed to the *Jatropha* hype by conveying overly optimistic claims about its agronomic suitability and economic potential. As explained in more detail below, some of these activities may have been linked with interests in selling *Jatropha* seeds and seedlings to farmers at inflated prices. As a result, many farmers began planting the new crop with little agronomic extension support, which has led to poor production and an unpredictable, scattered market for selling their seeds.

Anecdotal stories of farmers' disappointment attempting to grow *Jatropha,* especially when contrasted with the ubiquitous promotion of the crop in conferences and reports throughout the world, is the reason we embarked on this study. The scientific literature and news reports from around the world are increasingly documenting a growing disappointment about the crop's performance, especially in the marginal areas where it has been advertised to thrive. The fundamental goal of this study was to separate fact from fiction through an independent, objective collection and analysis of empirical data from current *Jatropha* farmers on the agronomic and economic realities of growing the crop.

The results of this survey, taken from interviews with hundreds of Jatropha farmers throughout Kenya, show extremely low yields and generally uneconomical costs of production. Based on our findings, Jatropha currently does not appear to be economically viable for smallholder farming when grown either within a monoculture or intercrop plantation model. The only model for growing *Jatropha* that makes economic sense for smallholders, according to actual experiences in the field so far, is growing it as a natural or live fence with very few inputs. Of course, this is precisely how *Jatropha* has been grown in this part of the world since it was introduced centuries ago.

Therefore, we recommend that the all stakeholders carefully reevaluate their current activities promoting Jatropha as a promising bioenergy feedstock. We also suggest that all public and private sector actors for the time being cease promoting the crop among smallholder farmers for any plantation other than as a fence.

Although these conclusions provide a sobering retort to some of the unbridled hype that has swirled around *Jatropha* over the past few years, current research and development may lead to improved varieties. What is clear from the results of this field survey, however, is that that day has not yet arrived.

Like anything, answers to complex problems like energy security and global warming require complex solutions. From this perspective, it is not hard to see that the promotion of a single silver bullet, like *Jatropha*, is a risky undertaking, especially in countries like Kenya where food security and poverty alleviation are the priority and critical agenda over resource uses. Even if *Jatropha* eventually pans out as a viable biofuel crop for smallholder farmers through agronomic improvements, other feedstocks will probably also still be needed to meet the challenges of a clean, domestic supply of energy. This is why the study also focuses on two other potentially viable oilseed crops in Kenya, *Castor* and *Croton*. Both native to and already growing throughout the country, the seeds from these species can provide high quality oil and may be grown more economically than *Jatropha*.

Castor seeds and the oil extracted from them already comprise substantial global markets for use in myriad industrial and pharmaceutical applications. *Although indigenous to Eastern Africa and highly suitable for growing in many parts of Kenya, Castor has not been grown commercially in Kenya since the 1970s.* Older farmers recall a time when traders would encourage them to grow *Castor* and guarantee a market for their production, although the market collapsed years ago. As part of the field survey, we visited 21 farms where *Castor* is still being grown, albeit in a haphazard and entirely non-commercial way. *Castor* also thrives in the wild throughout the country.

The study provides a detailed description of the agronomy and economics of *Castor* production, including an economic model of the returns that could be expected from both monoculture and fence plantations of the crop. We estimate three different yield scenarios based on the low, median, and high yields attained in the leading *Castor* growing countries of the world. *We conclude that Castor could present a positive investment opportunity under both the medium and high monoculture plantation scenarios and under all three fence plantation scenarios.* However, test trials should be conducted with different local and hybridized seeds to determine the best varieties for Kenya's agro-ecological zones and to accurately calculate the costs and benefits of growing *Castor* by smallholder and larger farmers.

One of the most promising oilseed sources in Kenya is from a native tree named Croton megalocarpus. Croton is widely adapted throughout Kenya, growing wildly on forest borders. Farmers also plant it for shade and wind protection. The seeds that fall from the tree are generally inedible, although some communities use it for chicken feed. A small handful of pioneering entrepreneurs have begun pressing oil from the seeds for biofuel. *Production is currently small — amounting to several thousand liters per months — but could be scaled up significantly due to the plentiful availability of the seeds and farmers' willingness to collect it for a reasonable price. However, like Jatropha, Croton has also not yet been domesticated for monoculture plantations, so will require further silvicultural research for significantly expanded production.*

2. Executive Summary

2.1 Study Overview

The primary purpose of this study was to collect and analyze a baseline of data on *Jatropha curcas* (*Jatropha*) in Kenya by administering a field survey of existing growers. The second purpose was to empirically evaluate the many varying claims about *Jatropha's* potential as a biofuels crop that have been generated over the past several years. The third purpose of the study was to collect similar data from farmers growing *Ricinus communis* (*Castor*) and *Croton m egalocarpus* (*Croton*), which are other potentially viable oilseed crops in Kenya. The fourth purpose was to conduct detailed Geographic Information System (GIS) mapping of each crop's potential suitability in Kenya. The final purpose was to test and analyze the chemical composition and performance of the oil produced from the three target crops in terms of their appropriateness for biofuel.

Due to the sporadic and previously undocumented nature of *Jatropha* activities in Kenya, as well as limitations on the resources available for this study, we chose to conduct a representative sample rather than a comprehensive census of current activities. The survey questionnaire consisted of six sections:

- Time and Location
- Background and Socioeconomic Status
- Agronomy, Land Use, and Opportunity Cost
- Description of Current Biofuels Activities
- Management and Economics
- Measurements and Yield

Each enumerator carried a Global Positioning System (GPS) tracking device to collect GIS coordinates for each farm. The data logs were later used to include average rainfall, temperature, and altitude information to the database, as well as to geotag photos taken throughout the survey. The fieldwork was conducted in February and March 2009 by eight enumerators travelling across six Provinces, including: Coast, Eastern, Central, Rift Valley, Western, and Nyanza. In total, the enumerators visited 289 farms growing *Jatropha*, 71 growing *Croton*, and 20 growing *Castor*. For calculation of yields, we conducted statistical analysis to verify our initial findings. A detailed description of that analysis is included in the section on *Jatropha* yields below.

This study went through an extensive peer review involving dozens of renowned local and international experts and practitioners. Numerous valid comments were raised and incorporated where possible. However, it is in the nature of peer reviews that not every comment can and should be addressed. The authors accept full responsibility of the substantial content of the study and its conclusion.

2.2 Jatropha

Jatropha curcas (*Jatropha*) is a multi-purpose, shrubby, tree belonging to the *Euphorbiaceae* family. It is native to Mexico or Central America, but now thrives in many parts of the tropics and sub-tropics in sub-Saharan Africa and Asia. *Jatropha* has received tremendous attention around the world over the past several years due to its potential as a biofuel crop. However, many of the claims made regarding *Jatropha* — including wide adaptability to diverse climatic zones and soil types, short gestation period, easy multiplication, drought tolerance, not competing with food production, and pest and disease resistance — have proven highly exaggerated. The fundamental purpose of this study was to test these and other claims against the reality of *Jatropha* being grown in Kenya.

Jatropha is a small tree or large shrub, which can reach a height of three to five meters under normal conditions, and as much as eight to ten under favorable conditions. *Jatropha* has been known for many years throughout the world as a multi-purpose tree with myriad traditional uses.

It is only within the past few years that *Jatropha* has been hailed as a biofuel crop around the world and, in particular, its purported ability to thrive in marginal conditions. However, many of the claims made regarding *Jatropha* — including wide adaptability to diverse climatic zones and soil types, short gestation period, easy multiplication, drought tolerance, not competing with food production, and pest and disease resistance — have proven highly exaggerated. From the farmer's point of view, both large- and small-scale, *Jatropha's* true potential as a cash crop depends on the successful development of the agronomy needed to domesticate what is essentially a semi-wild plant, as well as the creation of a market that ensures farmers can sell their seeds at a reasonable price. The fundamental purpose of this study was to empirically evaluate the above and other claims against the reality of *Jatropha* being grown in Kenya.

2.2.1 Agronomy

The basic agronomy of growing *Jatropha* as a plantation crop, instead of as a minor component of an agroforestry scheme, is not well understood or documented. Nevertheless, a continuous stream of sometimes specious claims persist regarding everything from *Jatropha's* wide environmental adaptability, invulnerability to pests and diseases, high yields with low input requirements, and ability to restore soils. After several years of experience growing *Jatropha* in Africa and elsewhere, many farmers and policymakers are beginning to realize that *Jatropha* is not the panacea it has been hyped to be.

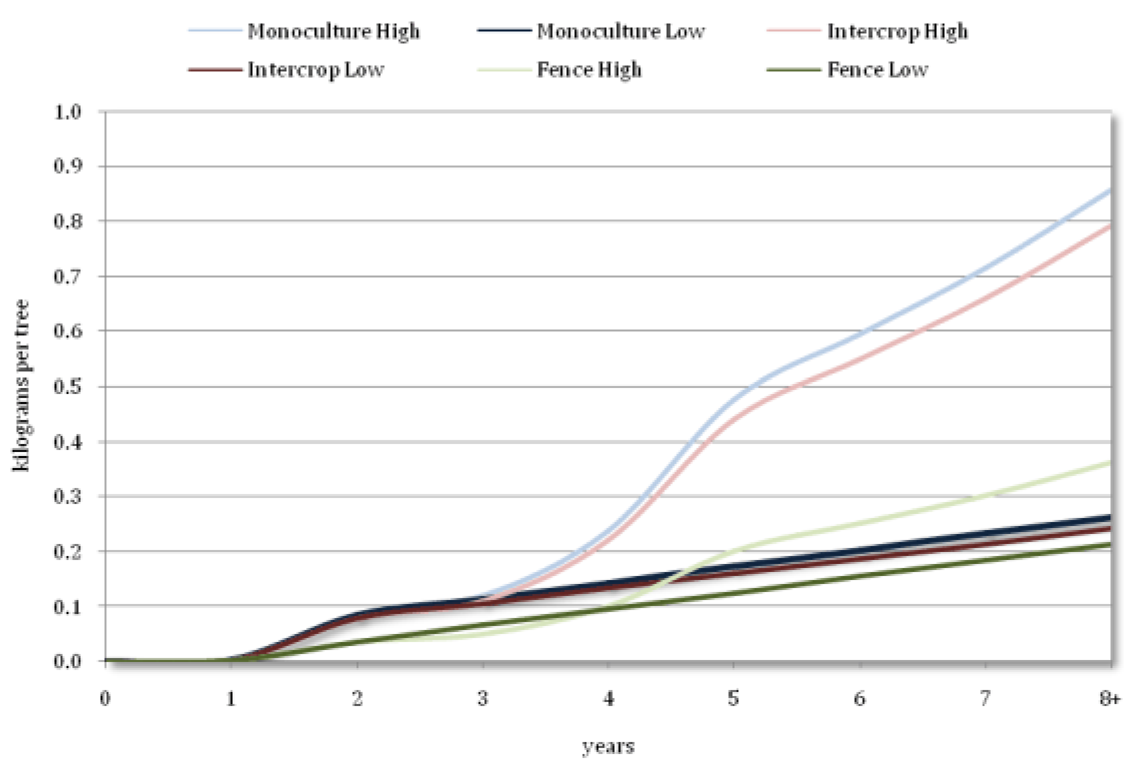
Jatropha's reputation for wide environmental adaptability may not always guarantee high yields. Recent observations of plantations across developing regions confirm that *Jatropha* may survive precipitation as low as 300 mm, but will not produce significant quantities of seeds at those levels. Although much has been written about the agronomic parameters within which *Jatropha* will grow and thrive, very little is actually known about what conditions are actually optimal for obtaining the highest yields.

Some authors claim that few, if any, pests and diseases afflict *Jatropha*. This is generally attributed to the plant's toxicity and insecticidal qualities. These claims have been quite roundly disproven by empirical evidence from the field, which shows that *Jatropha* is susceptible to many pests and diseases. More than three-quarters of *Jatropha* farmers in Kenya reported at least one pest or disease in the previous year, including, but not limited to: golden beetle, leaf spotting, mildew, fungus, and others.

Like most statistical analysis of survey information, the compilation of the yield data was complicated by inconsistencies in the raw data, commonly referred to as noise. The two main causes of noise are errors of data collection or inaccurate estimation of yields provided by farmers. As explained in detail in the main body of the study, we removed a total of 146 cases out of a total of 289 farms surveyed due to problems with data collection and anomalously low yields reported from one region in particular. The remaining 143 cases were then analyzed according to plantation age and type.

The limited amount of data available, especially for plantations three years and older, required us to estimate growth for later years. We used two scenarios to do this. The first, or "low" scenario simply continues the same rate of growth observed during the first four years, while the second, or "high" scenario, applies the rate of growth based on reports of *Jatropha* growing in marginal lands in India. The following chart and table show the results graphically and tabularly.

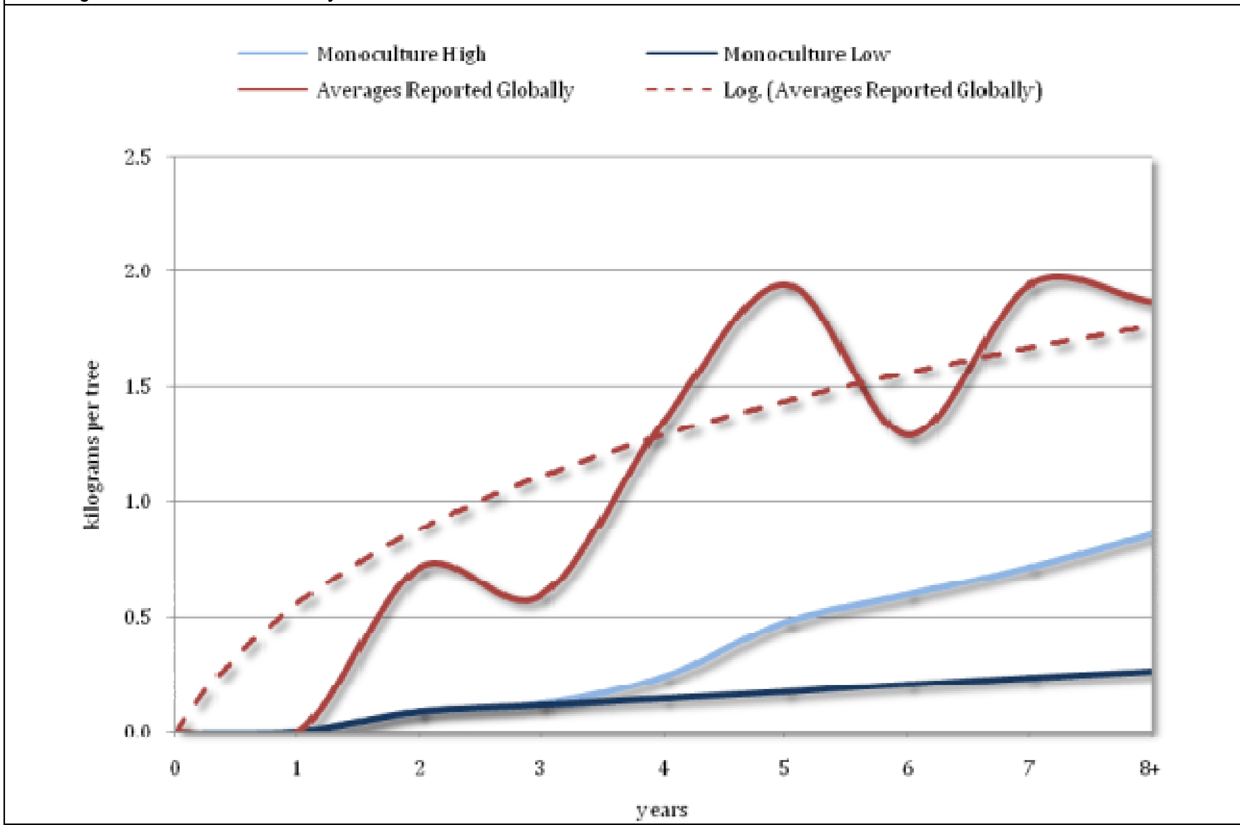
Observed and Projected *Jatropha* Yields by Plantation Type and Age



Observed & Projected Jatropha Yields by Plantation Type and Age (kilograms per tree)									
	Monoculture			Intercrop			Fence		
	Actual	Low	High	Actual	Low	High	Actual	Low	High
Year 0	0			0			0		
Year 1	0.004			0.002			0.002		
Year 2	0.085			0.079			0.036		
Year 3	0.063	0.115	0.119	0.015	0.106	0.110	0.059	0.066	0.050
Year 4	0.016	0.144	0.238	0.428	0.133	0.220	0.100	0.095	0.100
Year 5	0.800	0.174	0.476	0.202	0.160	0.440	0.535	0.125	0.200
Year 6		0.204	0.595		0.187	0.550		0.155	0.251
Year 7		0.234	0.714		0.214	0.660		0.184	0.301
Year 8+		0.263	0.857		0.241	0.793		0.214	0.361

Yields reported in the literature from around the world are significantly higher than those found in Kenya. In order to compare reported yields to those in Kenya, we averaged the yields per tree that were available from the literature for each age class regardless of the agro-climatic conditions. The variability of reported yields is underscored by the uneven growth curve from year zero through eight, but nonetheless shows a trend, which we have mapped in the following Chart.

Average Global Yields vs. Kenyan Yields



The current conclusion, based on experiences in Kenya and recent reports from around the world, is that Jatropha is not a wasteland crop. It needs fertilizer, water, and good management. And even then, results are unpredictable. Most reports on *Jatropha* seed yields do not distinguish what variables, i.e., planting materials' quality, agro-climatic conditions or management, are believed to have most influenced yields. Part of the reason for this is the lack of scientific research trials that can isolate different factors over multiple years to discern the relevant significance of each on yield.

2.2.2 Economics

As with any crop, the economic viability of *Jatropha* seed production is a factor of production cost, yield, and market price. This section presents a cost-benefit analysis for a model one-acre smallholder farm, based on costs, yield, and market prices from the survey. The analysis contains the three plantation types commonly found in Kenya and other parts of the developing world: monoculture, intercrop, and fence, with decreasing scales of tree density per acre and of management (costs incurred on hired labor, inputs and implements) intensity. Each scenario is modeled with both low and high yields, based on average yields in Kenya for each plantation type as observed in the field survey for years one through four, and a low case and high case projection from year five onward. The price of the seeds was assumed at 15Ksh [per kilo (1KSH = 0.01252 US$, 01.07.2009).

Considering the amount of attention *Jatropha* has received in the media, government, and the private sector, the results are quite sobering. The monoculture plantation model does not turn a net profit under either scenario.

Net Margin Over 10 Years, One-Acre Monoculture *Jatropha* Plantation

Years	0	1	2	3	4	5	6	7	8	9	Totals
Net Low (Ksh)	-10,314	-8,542	-6,653	-7,038	-7,226	-6,505	-7,217	-6,946	-6,664	-6,664	-73,769
Net Hi (Ksh)	-10,314	-8,542	-6,653	-6,999	-6,314	-3,574	-3,422	-2,288	-900	-900	-49,905

The intercrop plantation model is never profitable due to large input costs and relatively low yields and spacing density (see Table 21 and Chart 17).

Net Margin Over 10 Years, One-Acre Intercrop *Jatropha* Plantation

Years	0	1	2	3	4	5	6	7	8	9	Totals
Net Low (Ksh)	-6,177	-4,400	-4,985	-4,374	-4,722	-4,190	-4,743	-4,660	-4,558	-4,558	-47,366
Net Hi (Ksh)	-6,177	-4,400	-4,985	-4,359	-4,392	-3,127	-3,365	-2,968	-2,463	-2,463	-38,699

Only the fence plantation looks like a potentially appealing investment due to low cost requirements. Under both scenarios, the fence plantation turns an annual profit in year three (see Table 22 and Chart 17).

Net Margin Over 10 Years, One-Acre Fence *Jatropha* Plantation

Years	0	1	2	3	4	5	6	7	8	9	Totals
Net Low (Ksh)	-1,618	-545	-836	373	574	783	1,011	1,212	1,441	1,441	3,836
Net Hi (Ksh)	-1,618	-545	-836	251	612	1,354	1,743	2,104	2,561	2,561	8,187

The cumulative return is profitable after seven years under the high fence scenario and eight years for the low fence scenario. The internal rates of return for the high and low fence plantation model are 24% and 15%, respectively, which represent attractive agricultural investments.

2.2.3 Production in Kenya

While *Jatropha* is not indigenous to Kenya, it has been naturalized in many parts of the country. Farmers have also been growing it for many decades for reasons other than biofuels. Through the course of the field survey, many trees older than 30 years, and in some cases older than 50, were found being grown as fences or in the wild.

In the year 2000 or so, a few individual farmers in western Kenya along the Ugandan border, such as Siaya, Vihiga, and Bungoma West Districts, began introducing *Jatropha* as feeders to support their vanilla vines. The *Jatropha* was planted not for its production of oilseed, but rather to serve as a host for the more lucrative vanilla crop, which can fetch up to Ksh 3,000 per kilogram. As a result no effort was made to nurture the *Jatropha* to produce seeds.

It is only within the past few years that *Jatropha* has become widely known as a potential biofuel feedstock in Kenya. As word spread of this crop, large numbers of farmers, especially smallholders, began planting. Much of the initial enthusiasm came from a handful of NGOs (see Case Studies below). Farmers were recruited with information mainly taken from the Internet, as few, if any, of these early promoters had conducted any multi-year research trials of their own to verify the claims they were making on productivity.

The initial impression was that *Jatropha* would produce prolifically with little or no inputs, even in marginal semi-arid areas. Desperate for new promising crops in which to invest, farmers agreed to purchase seeds for as much as Ksh 2,000 per kilogram that were often advertised as "certified" even though they were basically collected from older trees growing in the wild or around farms. The farmers were also promised extension services to support growing the crop, as well as a market for the seeds once the plants started producing. Unfortunately, many farmers surveyed reported having little, if any, support since planting and few, if any, buyers for the small quantities of seeds they have managed to produce. With yields much lower than originally anticipated, many farmers have abandoned the crop.

Although most activities related to *Jatropha* consist of small-scale production involving NGOs and private companies working with outgrowers or with small demonstration/trial plots, stories of large-scale plantations continue to be reported. Most of these large projects involve foreign investors planning to plant thousands of acres on semi-arid land owned by the government or large private ranches. As of the date of this paper, no large plantations have commenced. Most of the ongoing activities consist of rather small-scale production involving NGOs and private companies working to promote planting by clusters of smallholder farmers.

2.2.4 Outlook, Potential and Obstacles

Jatropha could be a complementary component of a diverse livelihood strategy that contributes to overall increased agricultural productivity. These strategies include investing income earned from biofuels crops into agricultural inputs to improve yields of food crops, providing alternatives to charcoal and firewood for lighting and cooking, and better utilization of resources in disadvantaged locations. However, the lack of scientific knowledge on agronomy, such as high-yielding seeds, best management practices, and optimum soil fertility, inhibits the delivery of effective farmer extension services. Another obstacle is that most growers are geographically dispersed and have yet to produce large enough quantities of seeds to achieve the economies of scale necessary for efficient biofuels processing. A final problem involves whether smallholder farmers with little access to capital can afford to wait the years it will take to recoup their investment and start making a profit.

Based on the in-depth field research that serves as the foundation of this study, and the economic analysis we have conducted using actual costs and yields, we conclude that smallholders in Kenya should not pursue Jatropha as a monoculture or intercrop plantation crop at the present time. It simply makes no economic sense for farmers to be investing in a crop that will fail to yield positive returns, or fail to do so within a reasonable timeframe. *Further investments in monoculture and intercrop plantations by smallholders should be delayed until more research leads to yields high enough to justify the investment.*

The only type of Jatropha plantation that we can recommend for smallholders at this time is the fence. Not only does this survey show that a *Jatropha* fence can be a sound investment for the farmer, but it is also a widespread, existing use of *Jatropha* that farmers are aware of and would likely be willing to adopt quite easily without reducing food production. The fence also has the additional benefit of protecting valuable plantation crops from trespassing wildlife and people.

The potential for oilseed production from the widespread adoption of Jatropha fences is limited from the perspective of large, commercial biodiesel production, but could play a significant role in the local production and use of various bioenergy products. For example, if 25,000 farmers each fenced one acre of land, enough seeds could be produced after seven or eight years to produce between 681,250 and 1,143,750 liters of oil and between 2,043,750 and 3,431,250 kilograms of eco-charcoal, fertilizer, or biogas feedstock annually. Such production would also mean between Ksh 30 million and Ksh 64 million per year more in additional income to those farmers.

2.3 Castor

Ricinus communis (*Castor*) is a perennial shrub from the Euphorbiaceae family with green, reddish to purple stems and finger-like leaves that likely originated in Abysinnia, or modern day Ethiopia. In the wild, *Castor* can reach up to 9 meters, but cultivated varieties generally grow to between 1-4 meters. Dwarf-hybrid varieties grow to an average height of between 0.9 to 1.5 m, compared with between 1.8 to 3.7 m for normal varieties.

Castor oil is a pale yellow, viscous, and generally odorless liquid. The oil is an ancient product that has been in use for thousands of years as lamp oil, unguents, medicines, and more recently, for a long list of industrial applications. *Castor* oil's high molecular weight, low melting point, low solidification point, and extremely high viscosity, make it one of the most valuable industrial oils. *Castor* oil has over 700 uses, from medicines and cosmetics, to plastics and other industrial applications, to biofuel.

2.3.1 Agronomy

Castor is indigenous to Kenya, but considered invasive in other parts of the world. It can be grown as an annual or perennial and is suitable for manual harvesting as well as mechanization on a large scale. Many pests and diseases are reported to affect *Castor*, including up to 50 species of insects. Only five out of the 21 farms visited that were growing *Castor* reported any pests or diseases associated with the crop. Only one farmer reported using any type of pest control, which included applications of ashes around the plant and on the leaves.

The average yield in the six largest *Castor* producing countries in the world in 2007 was 401 kilograms per acre. Reports from India indicate yields as low as 350 kilograms per acre, which may be closer to reality for many smallholders in more marginal areas. Irrigated *Castor* is reported to yield between 800 and 1,600 kilograms per acre. The oil content of the seeds ranges from 35-55%. Thus, one tonne of seeds will yield between 365 and 573 liters, factoring in *Castor* oil's density of 959.3 kilograms per tonne of oil.

2.3.2 Economics

The economics of *Castor* production is well understood in many parts of the world where production is high, such as India and China. A dynamic market exists for various grades of *Castor* oil. Commercial *Castor* production in Kenya is virtually nonexistent despite the fact that the species is indigenous to the region.

Castor Yield, Production (2007) and Producer Price (2006) from Six Largest Producing Countries

Country	Yield (kgs/acre)	Area Harvested (acres)	Production (tonnes)	Producer Price (US$/tonne)
India	496	2,124,200	1,053,603	$377
China	387	543,400	210,296	$325
Brazil	280	403,929	113,100	$207

Ethiopia	419	35,815	15,006	$246
Paraguay	486	24,700	12,004	$153
Thailand	338	32,446	10,968	$234

This analysis is based on costs of production for similar crops being grown by smallholder farmers in Kenya. Two scenarios are presented: a one acre monoculture plantation with 2,646 plants spaced 1.5 meters by 1 meter apart, and a fence spaced 0.5 meters around the perimeter of a one acre plot of land. Yield and price data is taken from estimates from other parts of the world where *Castor* is being produced.

The net margin for the low yield monoculture plantation is negative. If medium or high yields are achieved, we estimate that the net margin is positive in all but the year of planting: the first and sixth.

Net Margin Over Ten Years, One-Acre Monoculture *Castor* Plantation										
Net Margins Plantation	1	2	3	4	5	6	7	8	9	10
Low (Ksh/acre)	-9,827	-367	-367	-367	-367	-5,117	-367	-367	-367	-367
Med (Ksh/acre)	-7,407	2,053	2,053	2,053	2,053	-2,697	2,053	2,053	2,053	2,053
High (Ksh/acre)	-5,507	3,953	3,953	3,953	3,953	-797	3,953	3,953	3,953	3,953

The fence plantation operates at an annual profit in all but the first year for all three yield scenarios. The monoculture plantation breaks even on the investment in year five for the medium yield and year three for the high yield (the low yield monoculture scenario never breaks even). For fence, the low scenario breaks even in year eight, the medium and high scenarios begin turning an overall profit in years four and three, respectively.

Net Margin Over Ten Years, One-Acre Fence *Castor* Plantation										
Net Margins Fence	1	2	3	4	5	6	7	8	9	10
Low (Ksh/acre)	-1,919	329	329	329	329	69	329	329	329	329
Med (Ksh/acre)	-1,539	709	709	709	709	449	709	709	709	709
High (Ksh/acre)	-1,259	989	989	989	989	729	989	989	989	989

2.3.3 Production in Kenya

Despite its local origins, and the global demand for *Castor* oil, Kenya does not currently produce any on a commercial scale. Many remember widespread interest in cultivating *Castor* in the 1970's and 1980's that resulted in large part from a governmental program promoting the crop. As a result, large numbers of farmers planted *Castor* in their fields, but the program quickly collapsed due to the lack of any established market for buying and processing the seeds.

We found *Castor* growing in all of the six regions covered by the survey, although with little if any effort towards commercial production. Every farm growing *Castor* was either using it as a natural fence or intercropped with a variety of food crops. None of the farmers reported selling any of the seeds harvested from the *Castor* trees, nor did they indicate any available market for *Castor* seeds. With global demand for *Castor* steadily increasing, an opportunity currently exists to restart a domestic *Castor* production industry, which could market the oil for a number of uses, including biofuels, both within Kenya and for export.

2.3.4 Outlook, Potential and Obstacles

The revival of *Castor* production in Kenya could be a boon to smallholder farmers and others. The crop is suitable to be grown throughout the country, a mature market exists both domestically and internationally, and processors are waiting to develop the industry. Even if the market for liquid biofuels is unattractive, alternative markets exist for Castor oil. *Kenya alone imports about 400 tonnes of high-quality Castor oil per year. That amounts to about 1,000 tonnes of seed, which would require between 2,260 and 4,200 acres to grow, which is equivalent to about Ksh 15-20 million in new farmer income.*

Of course, there are challenges to successfully launching a new Castor production industry in Kenya. First and foremost is the lack of experience growing and processing the crop. *Trials must be established by private sector interests and research institutions to create local knowledge on agronomy, as well as to create reliable sources of high-quality planting material.* Local processers must also import the machinery required to process high-quality Castor oil.

2.4 Croton

Croton megalocarpus (*Croton*) is a pan-tropical pioneer species that grows in cleared parts of natural forests, forest margins, and as a canopy. It is indigenous to Eastern and Southern Africa, but very closely resembles other *Croton* species growing throughout Africa. Although no formal tree population census has been conducted for *Croton* in Kenya, anecdotal evidence suggests millions of trees growing in the wild and on farms throughout the country.

Croton is a hardy, fast-growing deciduous tree with distinctive layering of branches, growing into a straight bole of between 6-36 meters. The crown is rather flat, providing light shade. *Croton* is a multi-purpose tree that provides a wide range of direct and indirect uses and services. Its timber is commonly used for making agricultural implements, in building construction, joinery and furniture, and for provision of posts and poles for fencing. *Croton* is also used for firewood and charcoal. The leaves, seeds, bark, roots, and wood extracts from *Croton* are used in a variety of human and veterinarian medicines, including the treatment of stomach ailments, malaria, wound clotting, and pneumonia.

Croton trees can have a range of positive and negative environmental impacts on soils, water, and air. As an indigenous species planted in homesteads, community centers and marketplaces, *Croton* provides shade and shelter and acts as a windbreaker. Mature trees have deep taproots, which access fertilization to augment soil nutrients, while root exudates enrich soil with minerals and leaf litter rich in nitrogen, phosphorus, and organic carbon. *Croton* trees improve and stabilize soil through water retention and erosion retardation, thus minimizing the loss of valuable topsoil and the siltation of rivers and lakes.

2.4.1 Agronomy

Croton is indigenous to Eastern and Southern Africa and is commonly found as a dominant upper story tree within evergreen rainforests, riverine gullies, and semi-arid and sub-humid highlands. *Croton* is widespread throughout a wide range of biophysical limits in Kenya. The tree flowers at the end of April and early May. After pollination by bees, fruit development takes several months, producing mature seeds in October through December in central and northern Kenya, and in January through February in western Kenya.

There is limited information available on pests and diseases affecting *Croton*, although there are reports of *Ambrosia* beetle and the insect *Scolytidae* preying on it, especially at altitudes of 1,300-2,100 meters. It is also reported to have an allelophatic relationship with *Striga* weed by triggering their germination, but is not parasitized by it. Its wood is vulnerable to attack by decay and stain fungi. According to the Kenya survey, only a small number of farmers reported any pests or diseases associated with the Croton trees growing on their farms.

Several factors influence yield: frequency of flowering, number of inflorescences, number of female flowers per inflorescence, number of seeds per fruit, and seed weight. Currently, there is scant information on yield per tree because of a historical lack of demand for the seeds. However, the potential yield of mature trees has been assessed at about 25 kilograms per year, with some projections as high as 50 kilograms per year. A systematic study is needed to determine yields under different growing conditions and within varied agro-ecological zones.

2.4.2 Economics

There is limited empirical data on the economics of growing *Croton* as either a biofuel or timber crop. As a result, we have designed a theoretical model to test *Croton's* value from the grower's perspective. The assumptions underlying the model are based on observations of growth and yield characteristics from mature *Croton* trees growing throughout Kenya by expert foresters from KEFRI, as well as from the scientific literature. The model analyzes two plantation types and four growing scenarios, each on one acre of land. The first is a monoculture plantation with 144 trees spaced 5 by 5 meters apart. The second type involves a living fence or hedge of 72 trees grown 3.5 meters apart along the outer perimeter of the plot. Both plantation types are considered for their value if grown strictly for oilseeds or if grown for both oilseeds and timber.

The annual net margins for the row plantation turn positive in year seven and grow to a maximum of Ksh 4,129 per acre by year ten. The fence plantation remains in the red even up to full maturity, and so never becomes profitable if only oilseeds are considered.

Net Margins Years 1-10, One-Acre Monoculture & Fence *Croton* Plantations

Net Margins Plantation	1	2	3	4	5	6	7	8	9	10
Ksh/acre	-30,536	-14,581	-9,961	-3,671	-2,731	-191	1,509	1,629	3,269	4,129
Net Margins Fence	1	2	3	4	5	6	7	8	9	10
Ksh/acre	-16,004	-6,476	-4,186	-3,436	-4,156	-2,756	-1,916	-1,726	-396	-236

However, when timber costs and revenues are included, the net margin starting in year 11 onward for the monoculture jumps to Ksh 22,089 per year. Including timber revenue for the fence makes the venture profitable from year 11 onward with an annual net margin of Ksh 7,284.

2.4.3 Production in Kenya

There are currently various activities involving *Croton* occurring at global, regional, and national levels. We encountered *Croton* growing on and around farms in all of the six regions covered by the survey, although mainly at higher elevations around Mt. Kenya and the Central highlands, and in parts of Western and Rift Provinces. In total, 73 of the 397 farms visited contained *Croton*. Only three farmers reported selling Croton seeds for oil. No other market currently exists for the seeds, at least amongst the farmers visited. Only two farmers were planting Croton in a monoculture plantation and both were quite small.

Endelevu Energy, the lead author of this study, is also working on a new venture under the name Endelea Energy to produce flex-fuel diesel generators capable of running on SVO. *Croton* oil is one of the key feedstocks being tested. The Kenya Forestry Research Institute (KEFRI) is involved in research for production, processing, and marketing of *Croton* for biofuels and reforestation.

The Naro Maru Help Self Help Group and Horizon Business Ventures at the base of Mt. Kenya has been producing *Croton* oil for biodiesel and straight vegetable oil (SVO) biofuel. The Enterprise Development Centre, a community-based organization also operating in the Mt. Kenya region, is carrying out a pilot project producing biodiesel from *Croton* seeds.

The Kakamega Education Environment Programme (KEEP) in Western Kenya is promoting forest conservation through schools, churches, and communities by encouraging nursery establishment and tree planting with *Croton*. The Kenya Medical Research Institute (KEMRI), in collaboration with universities and research institutions, is initiating studies on *Croton* as a source of medicinal extracts. In Tanzania, the Africa Biofuel and Emission Reduction (TZ) Limited is attempting to launch a large plantation and outgrower project for *Croton* oil.

2.4.4 Outlook, Potential and Obstacles

There are many hundreds of thousands, if not millions, of Croton trees growing wildly and in agroforestry systems throughout Kenya, but particularly near Mt. Kenya, Western Province, around the Mau Forest complex, and in and around Nairobi. Some of the critical obstacles for the development of *Croton* for biodiesel production include a lack of knowledge on the best silvicultural practices, such as spacing, pruning, and the correlation between fertilization of trees and yields. Seed harvesting and post-harvest handling techniques also have not been established and standardized. There remains a lack of seed processing methods for shelling seeds and oil extraction at the local level, where access to oil could have an immediate and significant affect on development. Capacity is limited at all levels along the *Croton* value chain.

Nonetheless the potential for production, processing and utilization of Croton seeds for biofuels is enormous. This is because *Croton* is an indigenous, multi-purpose, agroforestry species with wide climatic adaptability. It has been domesticated over many years without many known pests and diseases. Although systematic studies have yet to be done on yields per tree, especially for monoculture planting, it is suspected that yields may exceed 25 kilograms per tree. The oil content of the seeds is also appreciably high at 30%. Additionally, *Croton* seedcake may be a highly suitable animal feed, especially for poultry. The potential for processing seeds at local level into straight vegetable oil is attractive for use in lighting, cooking, and electricity generation from specially designed generators.

There is a need to design and establish agronomic research trials for determining best practices and identifying superior, seed-producing trees. There is also an urgent need to undertake countrywide census of different age classes of *Croton* trees and to determine accurate seed yield estimates. A final recommendation, mainly aimed at the private sector, is to design and mainstream an integrated model of production, processing, utilization, and marketing for *Croton*-based biofuel systems.

3. Study Overview

3.1 Purpose and Structure

The primary purpose of this study was to collect and analyze a baseline of data on *Jatropha curcas* (*Jatropha*) in Kenya by administering a field survey of existing growers. The data collected through the survey is a representative sample of common experiences and challenges growing this new crop. We analyzed the data to see if there are any significant trends as part of a detailed agronomic and economic analysis. The resulting analysis provides an opportunity to assess the current viability of growing *Jatropha* among smallholder farmers in developing countries like Kenya.

The second purpose was to empirically evaluate varying claims about *Jatropha's* potential as a biofuels crop that have been generated over the past several years. To this end, we conducted an extensive review of the current literature on *Jatropha*, which we then compared to our findings in Kenya. Chapter Four contains the complete survey findings and analysis regarding *Jatropha*.

The third purpose of the study was to collect similar data from farmers growing *Ricinus communis* (*Castor*) and *Croton megalocarpus* (*Croton*), which are other potentially viable oilseed crops in Kenya. The lack of commercial oilseed production from these two crops prevented the type of detailed analysis of empirical data that was conducted for *Jatropha*. Instead, the result provides a more illustrative sample of current activities and theoretical projections of their potential in Kenya. Chapter Five contains the complete survey findings and analysis regarding *Castor*, and Chapter Six contains the same regarding *Croton*.

The fourth purpose was to conduct detailed Geographic Information System (GIS) mapping of each crop's potential suitability in Kenya. Using multi-criteria selection, we combined three categories of data to deduce overall suitability. These include: agro-climatic suitability, market access, and current conflicts with competing agricultural production. A more in-depth explanation of the methodologies, data, and assumptions we used for the mapping are contained in Sections 4.4.4, 5.4.2, and 6.4.2.

The final purpose was to test and analyze the chemical composition and performance of the oil produced from the three target crops in terms of their appropriateness for biofuel. We conducted laboratory testing of the oils both in straight form and upon conversion to biodiesel. The testing parameters were based on international standards for both straight vegetable oil (SVO) biofuel and biodiesel. Complete results and descriptions of the relevance of the most significant testing parameters are included in Chapter Seven.

3.2 Survey Methodology

Due to the sporadic and previously undocumented nature of *Jatropha* activities in Kenya, as well as limitations on the resources available for this study, we chose to conduct a representative sample rather than a comprehensive census of current activities. We compiled a list of known *Jatropha* activities, including names and locations of farmers, from interviews with biofuels stakeholders from government, the private sector, and among non-governmental organizations (NGOs). Our enumerators also conducted focus group interviews with local government officials, farmers, and others involved with *Jatropha* within each district or division they visited during the survey. This approach enabled the enumerators to focus their time visiting the most active *Jatropha* farmers in each area, as well as to ensure a representative sample in terms of plantation size, age, and management type. The focus group interviews also provided valuable insights and opinions on *Jatropha* from various perspectives.

The survey questionnaire consisted of six sections:

- Time and Location
- Background and Socioeconomic Status
- Agronomy, Land Use, and Opportunity Cost
- Description of Current Biofuels Activities
- Management and Economics
- Measurements and Yield

Each enumerator carried a Global Positioning System (GPS) tracking device to collect GIS coordinates for each farm. The data logs were later used to include average rainfall, temperature, and altitude information to the database, as well as to geotag photos taken throughout the survey. For farmers who had planted different plots at different times, we collected data from the healthiest and most productive plots. For example, if a farmer had planted 0.25 acres in 2006 and 0.5 in 2007, the enumerator would assess which plot appeared to be performing best and then focus the specific survey questions on that particular plot.

We tested a draft version of the survey questionnaire with farmers in Central Kajiado District and adjustments were made. The fieldwork was conducted in February and March 2009 by eight enumerators travelling across six Provinces, including: Coast, Eastern, Central, Rift Valley, Western, and Nyanza. In total, the enumerators visited 289 farms growing *Jatropha*, 71 growing *Croton*, and 20 growing *Castor*. Survey data was entered into a spreadsheet by one of the study directors, a researcher at ICRAF, and a Masters student from University of Nairobi, interning at ICRAF.

Once entered, the data was organized and cleaned, and then transferred to the statistical analysis program called Statistical Package for the Social Sciences, or SPSS for short. Twenty-two of the 289 *Jatropha* surveys were found to have returned insufficient or inaccurate data, so were removed from the database. The majority of the data analysis was conducted in SPSS, including most of the information collected on agronomy, management, and economics. For calculation of yields, we consulted with Dr Joseph Ogutu of the International Livestock Research Institute (ILRI), one of the foremost statisticians in Kenya. Dr Ogutu used the Statistical Analysis System (SAS) to verify our initial findings on yields. A detailed description of that analysis is included in the section on *Jatropha* yields below.

3.3 Geographic Distribution and Types of Farms Visited

Central Province, located north of Nairobi, is one of the most fertile and densely populated regions in Kenya. Most of the farms visited in Central Province are located in the semi-humid and transitional zones (semi-humid to semi-arid), with elevations of 1,100 meters above sea level or higher. Soils are mostly black cotton and chalk. *Jatropha* activities in Central Province are relatively small in number, including mostly new plantations, nurseries, and a few old fences (nurseries were not counted in the descriptive statistics). Four percent of the 267 Jatropha farms visited with valid data were located in Central Province.

The largest proportion of *Jatropha* farms surveyed was located in Coast Province (54% of 267 farms). The main reason for this is the fieldwork from Shimba Hills in Kwale District, which was a focus of one of our enumerators due to the organized outgrower project occurring there (see Case Study on Energy Africa Ltd. in Chapter Four for more information on the activities in this area). Agro-climatically, most parts of Shimba Hills fall in the semi-humid zone, with an elevation ranging from 50-740 meters. Agro-climatic zones in other parts of Coast Province range from semi-humid along the coast of Malindi and Kilifi to transitional and semi-arid in Taita and Kinango inland of the coast. The dominant soil type in Shimba Hills is sand. Other parts of the coast contain loam and clay soils.

In Eastern Province, our enumerators visited farms in Kibwezi, Yatta, Kitui and Nzaui, which are among the regions where *Jatropha* plantations have been systematically promoted by a few key Kenyan NGOs (see Case Studies on the Green Africa Foundation and the Vanilla Jatropha Development Foundation in Chapter Four). Except some transitional zones in Kitui and Nzaui with an elevation over 1,100 meters, most parts of the region are semi-arid. Areas below 670 meters in Eastern Province are generally arid. Soil types vary between sand, clay, and loam.

In vast parts of Rift Valley Province *Jatropha* activities seem to be rather sporadic. One exception is Nguruman, where *Jatropha* has traditionally been planted as a hedge and or live fence. The agro-climatic conditions of the Province vary greatly (i.e. humid to semi-humid in Nandi Central with an elevation of 2,000 meters; transitional in Keiyo, Baringo, and Kajiado with an elevation ranging from 1,250-1,800 meters). The major soil types are loam and sand.

One team of enumerators visited farms in Bondo and Siaya in the north of Lake Victoria and another covered Homa Bay, Rachuonyo, Nyando in the eastern lake shore in Nyanza Province. Nyanza is another region, along with Coast and Eastern Provinces, where *Jatropha* was actively promoted among small famers. The region falls in agro-climatic zones ranging from humid in high-altitude areas (1,400-2,000 meters), sub-humid (1,200-1,400 meters), and semi-humid (1,100-1,300 meters), with diverse soil types throughout, though mainly loamy and black cotton.

Western Province is geographically small, but one of the most agriculturally favorable and densely populated regions in Kenya. Our enumerators visited Vihiga, Kakamega, Busia, Mumias, and Bungoma West Districts, most of which fall in the humid agro-climatic zone, which is one of the most productive maize and sugarcane zones in the country. *Jatropha* activities in Western Province are relatively small and sporadic, most likely due to the fact that the region has such favorable conditions for valuable food and cash crops.

Charts 1 and 2 show the geographic and agro-climatic distribution of *Jatropha* farms visited during the field survey. The definitions of the different agro-climatic zones are contained in Table 1. Map 1 (on the following page) provides the actual locations of each *Jatropha* farm surveyed.

Chart 1: Geographic Distribution of *Jatropha* Farms

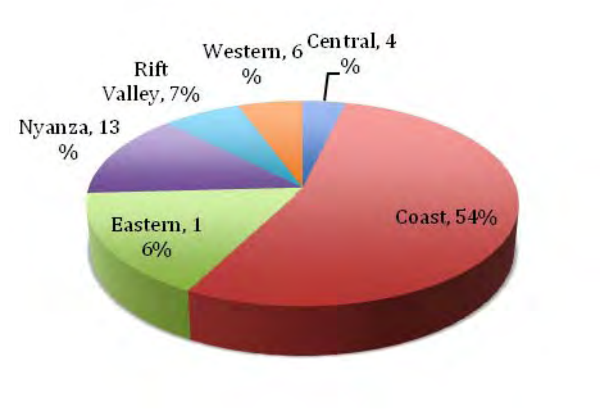


Chart 2: Agro-Climatic Distribution of *Jatropha* Farms

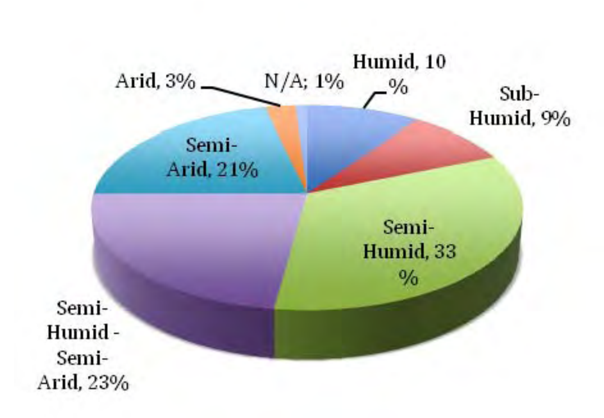
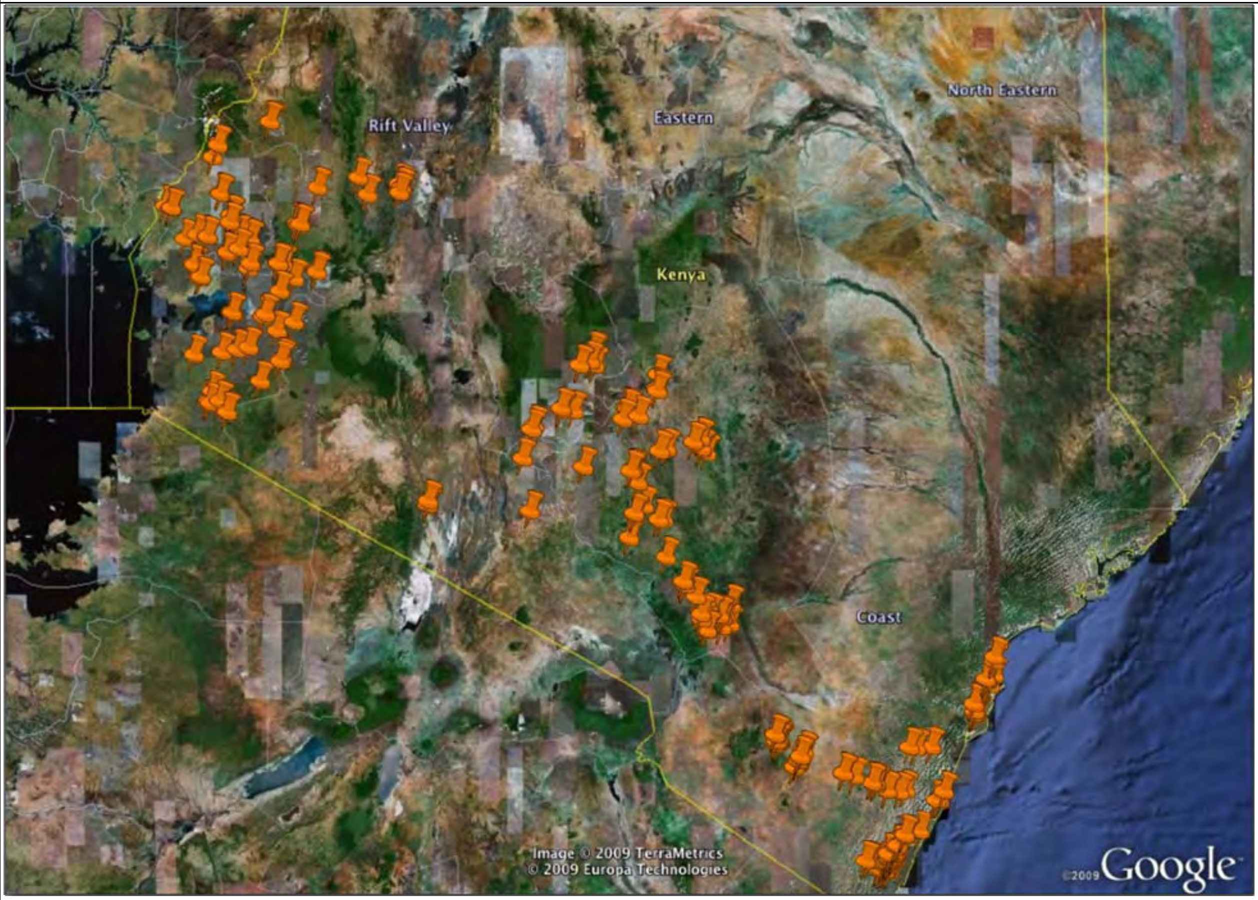


Table 1: Definitions of Agro-Climatic Zones

	Avg. Rainfall (mm)	Vegetation Type	Plant Growth Potential	Crop Failure Risk (Maize)
Humid	1100-2700	moist forest	very high	extremely low (0-1%)
Sub-Humid	1000-1600	moist and dry forest	high	very low(1-5%)
Semi-Humid	800-1400	dry forest-woodland	high to medium	fairly low (5-10%)
Semi-Humid/Semi-Arid	600-1100	dry woodland-bushland	medium	low (10-25%)
Semi-Arid	450-900	bushland and scrubland	medium to low	high (25-75%)
Arid	300-550	scrubland	low	very high (75-95%)
Very Arid	150-350	desert scrub	very low	extremely high (95-100%)

Map 1: Geographic Locations of *Jatropha* Farms Surveyed



3.4 Age Groups, Plantation Types and Plot Sizes of Farms Visited

Chart 3 shows that among the 267 *Jatropha* farms with eligible data, almost three-quarters were three years old or younger by the time of the survey in February 2009. Most of the farms older than three years were planted for reasons other than the production of oilseeds, such as for fencing or shade. As Chart 4 shows, intercropping with other food or cash crops was found to be the dominant plantation type, while monoculture and fence were found in similar proportions.

Table 2 breaks down the plantation types surveyed by age class. Intercrop is the dominant plantation type for farms three years old or less, followed by monoculture. By contrast, fence is the most common plantation type for plantations seven years or older. Over 90% of farms surveyed with *Jatropha* seven years or older were growing it for fencing. This demonstrates that intercrop and monoculture plantations started being adopted mainly as a result of the promotion of *Jatropha* over the past few years.

Chart 3: Age Distribution of *Jatropha* Farms

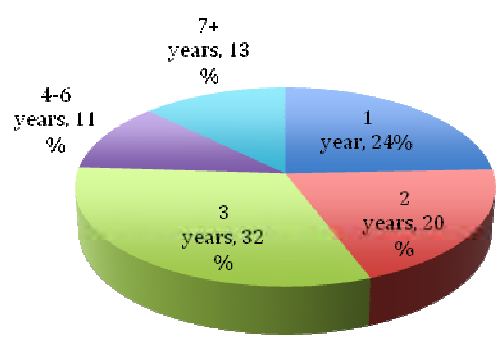


Chart 4: *Jatropha* Farms by Plantation Types

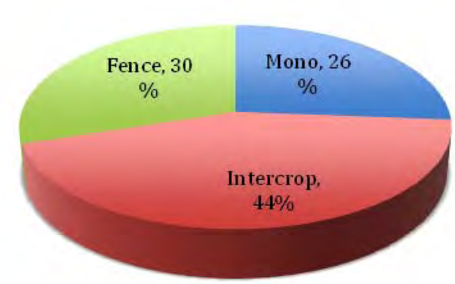


Table 2: Breakdown of Age and Plantation Type

	1 year	2 year	3 year	4-6 year	7+ year	Total
Monoculture (%)	14%	15%	35%	4%	2%	70
Intercrop (%)	38%	24%	40%	14%	1%	117
Fence (%)	13%	14%	10%	12%	31%	80
Number of Farms	65	53	85	30	34	267

Chart 5 and Table 3 show the distribution of plot size and age for the *Jatropha* farms surveyed. Overall, plot sizes were quite small, with those less than 0.25 acre comprising over 55% of all farms. Table 4 shows the minimum, maximum, mean, and median plot sizes for each plantation type. The total number of farms with valid data for land size is 257, rather than 267. The mean size for monoculture, intercrop and fence plantations was 0.9, 0.9, and 0.3 acres, respectively. The median size of all monoculture plantations was 0.5 acres; for intercrop and fence the median size was 0.25 and 0.05 acres, respectively. Over 94% of farms visited during the survey were smallholders (see Chart 6). The remaining 6% included NGOs, CBOs, private companies, and research institutes.

Chart 5: Size Distribution of *Jatropha* Farms (acres)

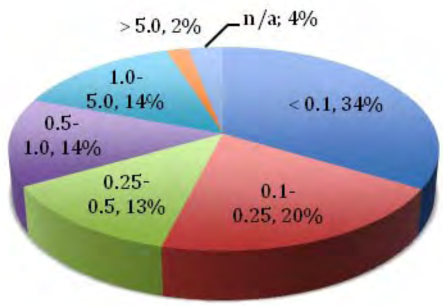


Chart 6: Ownership of *Jatropha* Farms

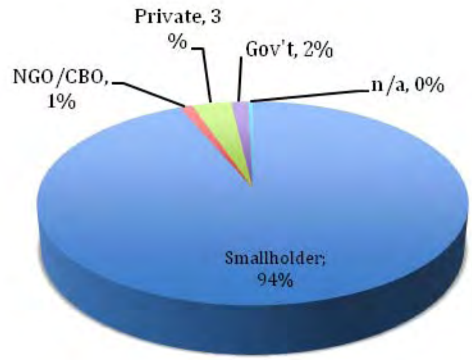


Table 3: Distribution of Plot Size & Age of *Jatropha* Farms

	1 year	2 year	3 year	4-6 year	7+ year	Total
< 0.1 acre	23	18	16	10	22	89
0.1 ≥ 0.25 acre	12	12	13	12	5	54
0.25 ≥ 0.5 acre	6	7	18	2	1	34
0.5 ≥ 1 acre	10	4	18	3	2	37
> 1 acre	9	12	17	3	2	38
Total No. of Farms	60	53	82	30	32	257

Table 4: Plantation Type and Size of *Jatropha* Farms

	Number	Min (acres)	Max (acres)	Mean (acres)	Median (acres)
Monoculture	68	0.012	7	0.9	0.5
Intercrop	114	0.0001	15	0.9	0.25
Fence	75	0.0004	8	0.3	0.05
Total	257	0.0001	15	0.7	0.25

4. Jatropha

Jatropha curcas (*Jatropha*) is a multi-purpose, shrubby, tree belonging to the *Euphorbiaceae* family.[vi] It is native to Central America, but now thrives in many parts of the tropics and sub-tropics in sub-Saharan Africa and Asia. *Jatropha* may have been distributed centuries ago by Portuguese seafarers via the Cape Verde Islands and Guinea Bissau to other countries in Africa and Asia. Over the past several years *Jatropha* has received tremendous attention around the world due to its potential as a biofuel crop.[vii] However, many of the claims made regarding *Jatropha* — including wide adaptability to diverse climatic zones and soil types, short gestation period, easy multiplication, drought tolerance, not competing with food production, and pest and disease resistance — have proven highly exaggerated.[viii] The fundamental purpose of this study is to test these and other claims against the reality of *Jatropha* being grown in Kenya.

Left: Silas Mureithi posing with one of ten *Jatropha* trees planted as a fence seven years ago on his 17-acre farm in Kilifi District, Coast Province. Middle: Nicholas Somba Ngau standing next to an eight-and-a-half year old *Jatropha* fence on his farm in Nzaui District, Eastern Province. Right: Dried *Jatropha* seedpods ready to be hulled.

4.1 Overview

4.1.1 Names

Scientific Name: *Jatropha curcas* Linnaeus

Common Names: physic nut, purging nut (English); mbono (Swahili); pourghère, pignon d'Inde (French); purgeernoot (Dutch); purgiernuß, brechnuß (German); purgueira (Portuguese); fagiola d'India (Italian); dand barrî, habel meluk (Arabic); kanananaeranda, parvataranda (Sanskrit); bagbherenda, jangliarandi, safed arand (Hindi); kadam (Nepal); yu-lu-tzu (Chinese); sabudam (Thailand); túbang-bákod (the Philippines); jarak budeg (Indonesia); bagani (Côte d'Ivoire); kpoti (Togo); tabanani (Senegal); mupuluka (Angola); butuje (Nigeria); makaen (Tanzania); piñoncillo (Mexico); coquillo, tempate (Costa Rica); tártago (Puerto Rico); mundubi-assu (Brazil); piñol (Peru) and pinón (Guatemala).[ix]

Jatropha flowering on a farm in Bungoma, Western Province.

The genus *Jatropha* belongs to tribe *Joannesieae* of *Crotonoideae* in the *Euphorbiaceae* family and contains approximately 170 known species.[x] The genus name *Jatropha* derives from the Greek *iatrós* (doctor) and *trophé* (food), which implies medicinal uses.[xi] *Curcas* is the common name for physic nut in Malabar, India.[xii] The father of modern taxonomy, Carl Linnaeus, was the first to name the physic nut *Jatropha curcas* according to the binomial nomenclature of "Species Plantarum."[xiii] Scientists Bijan Dehgan and Grady Webster have postulated that *Jatropha curcas* is the most primitive form of the *Jatropha* genus.[xiv]

Jatropha fruits dried and ready for harvesting.

4.1.2 Description

Jatropha is a small tree or large shrub, which can reach a height of three to five meters under normal conditions, and as much as eight to ten under favorable conditions.[xv] The tree is deciduous, meaning it sheds its leaves in the dry season.[xvi] The plant is monoecious, or hermaphroditic, meaning each individual contains both male and female reproductive elements, while the terminal inflorescences contain unisexual flowers.[xvii] After pollination by insects, the inflorescences form a bunch of green ellipsoidal fruits.[xviii] Flowering occurs during the wet season or throughout the year in permanently humid regions.[xix] Each inflorescence yields a bunch of approximately 10 or more ovoid fruits.[xx] With good rainfall conditions nursery plants may bear fruits after the first rainy season, and directly sown plants after the second rainy season.[xxi]

A three, bivalved cocci is formed after the seeds mature and the fleshy exocarp dries.[xxii] The blackish seeds mature about 3–4 months after flowering.[xxiii] Depending on the variety, the decorticated seeds may contain 19-59% of oil.[xxiv] The oil contains more than 75% unsaturated fatty acid.[xxv] The fatty acid composition of oil is dominated by oleic and linoleic acids, which makes it potentially useful in the surface coating industry and for other applications.[xxvi]

Table 5 contains the mean and median age, height (meters at breast height), number of branches, and number of fruits per branch from the 267 *Jatropha* farms that we visited with valid data. Much of the *Jatropha* was not flowering due to the time of year of our visits.

Table 5: Physical Characteristics of *Jatropha* Surveyed

Age (years)		Height (mbh)		# of Branches		# of Fruits	
mean	median	mean	median	mean	median	mean	median
3.9	2.5	2.1	1.8	18.5	9.5	4.0	0.0

4.1.3 Uses

Jatropha has been known for many years throughout the world as a multi-purpose tree with myriad traditional uses, including: cooking salt from the ashes of the roots and branches, food garnish from stewed or steamed leaves, fuel from fruit hulls and shells, dyes and tannins from leaf juice and ashes, and wool spinning and textile manufacture from the oil. The bark contains a wax composed of a mixture of melissyl alcohol and its melissimic acid ester, the oil is used as fish poison and pesticide, leaf extracts have been effective in controlling *Sclerotium spp.*, an *Azolla* fungal pathogen, the nuts have been used as a purgative, and the latex has antibiotic properties against *Candida albicans*, *Escherichia coli*, *Klebsiella pneumoniae*, *Staphylococcus aureus* and *Streptococcus pyogens*.[xxvii]

It is only within the past few years that *Jatropha* has been hailed for its potential as a biofuel feedstock and, in particular, its purported ability to thrive in marginal conditions. From the farmer's point of view — both large- and small-scale — *Jatropha's* true potential as a cash crop depends on the successful development of the agronomy needed to domesticate what is essentially a semi-wild plant, as well as the creation of a market that ensures farmers can sell their seeds at a reasonable price. Some *Jatropha* projects also are being promoted for the local production and consumption of the oil for use in stoves, lamps, and for local energy production.

Uncollected *Jatropha* fruits.

Although the seedcake that remains after pressing *Jatropha* oil contains high-quality proteins, it also contains various toxins, such as phorbol esters, curcin, trypsin inhibitors, lectins, and phytates.[xxviii] Thus, one of the most valuable uses of the seedcake – as an animal feed – is not a viable option without expensive detoxification processing.[xxix] However, the seedcake is valuable as an organic nutrient source, as it contains more nutrients than chicken and cattle manure.[xxx] The presence of the biodegradable toxins, mainly phorbol esters, makes the fertilizing cake potentially suitable as a pesticide.[xxxi]

The seedcake can also serve as feed for biogas production through anaerobic digestion before it is applied as fertilizer.[xxxii] Recycling of byproducts from *Jatropha* oil processing, such as seedcake for fertilizer, can help reduce inputs needed for both *Jatropha* cultivation and other agricultural crops or it can produce extra energy in the form of biogas.[xxxiii]

4.1.4 Environmental Impacts

One of *Jatropha's* most attractive characteristics is its claimed ability to withstand drought and to grow in semi-arid areas with poor soil fertility. *Jatropha* may be used to control soil erosion, especially in semi-arid areas, and its seedcake can be used to improve soils, as mentioned above. As a natural fence, *Jatropha* can assist farmers in preventing conflicts with endangered wildlife.

The *Jatropha* biofuels value-chain may lead to significant reductions in greenhouse gas emissions, although more research is necessary to ascertain these impacts over the entire life cycle of growing, energy production, and use. Existing research indicates that biodiesel production from *Jatropha* is predicted to be generally positive in comparison to the use of fossil diesel, although the significance of this positive energy balance depends on the specific methods for growing, transporting, and processing, which tend to be project specific.[xxxiv] However, land-use changes associated with new plantations, especially on land not previously used for agriculture, can require years of new plant growth to re-sequester the carbon that is lost during land clearing.

Jatropha's toxicity may present potential environmental and public health problems. One researcher has warned that the curcanoleic acid contained in the oil may promote skin cancer and that the oil can cause skin irritation to farm workers.[xxxv] *Jatropha* is also considered invasive in many parts of the world, including South Africa, Hawaii, and Australia.[xxxvi]

4.2 Agronomy

This section evaluates the accuracy of the current research on various aspects of *Jatropha's* agronomy from different parts of the world compared with the empirical findings from this survey. The basic agronomy of growing *Jatropha* as a plantation crop, instead of as a minor component of an agroforestry scheme, is not well understood or documented.[xxxvii] In fact, we are not aware of any existing survey similar to this one, at least in the public domain. Nevertheless, a continuous stream of sometimes specious claims persist regarding everything from *Jatropha's* wide environmental adaptability, invulnerability to pests and diseases, high yields with low input requirements, and ability to restore soils.[xxxviii] As one expert explains, many of these exaggerated claims are based on "incorrect combinations of unrelated observations, often based on singular or elderly [*Jatropha*] trees."[xxxix] After several years of experience growing *Jatropha* in Africa and elsewhere, many farmers and policymakers are beginning to realize that *Jatropha* is not the panacea it has been hyped to be.[xl]

Wilson Kyalo amidst the 2,500 *Jatropha* trees he planted 14 months before on his 11-acre farm near Machakos in Eastern Province. The plot has yet to begin producing seeds.

4.2.1 Agronomic Parameters

Jatropha's reputation for wide environmental adaptability may not always guarantee high yields. Recent observations of plantations across developing regions confirm that *Jatropha* may survive precipitation as low as 300 mm, but will not produce significant quantities of seeds at those levels.[xli] On the flipside, high humidity or rainfall can result in fungal attacks to which the plant is sensitive. Although much has been written about the agronomic parameters within which *Jatropha* will grow and thrive, very little is actually known about what conditions are actually optimal for obtaining the highest yields.

A recent survey of agronomic conditions for 241 herbarium specimens collected throughout Mexico and Central America, as well as 83 plantations throughout the world, indicate that *Jatropha's* natural agronomic range includes areas with higher precipitation than the areas in which it has been promoted and is being planted.[xlii] The authors of this survey concluded as follows:

> "The results demonstrate that *Jatropha* is not common in regions with arid and semi-arid climates and does not naturally occur in regions with [average annual precipitation] of less than 944 mm year. This contrasts with popular claims on preferred climate…and with the limiting rainfall levels stated in recent literature, ranging from 200 mm to 300 mm, yet agrees well with the observation that production in sites with 900–1200 mm rainfall can be up to double (5 t dry seed ha 1 yr 1) of the production in semi-arid regions (2–3 t dry seed ha 1 yr 1). It indicates that plantations in arid or semi-arid regions (19.5% of the sampled plantations in this study) may show a low productivity or need additional irrigation."[xliii]

Table 6 summarizes the study's findings for the range and optimal rainfall and temperature. The range includes the entire spectrum of rainfall and temperature found at all sites including both the herbarium samples and the plantations. The optimal temperature includes the range of temperatures where *Jatropha* was found to grow naturally, according to the herbarium samples. The optimal rainfall includes the lower estimate reported by Ouwens et al., and the upper estimate for optimal rainfall includes the upper limit of the 25-75% percentile of *Jatropha* growing naturally, according to the herbarium samples.[xliv] The altitude range is taken from Achten et al., although no optimal altitude could be identified in the literature.[xlv]

Table 6: Range and Optimal Agronomic Suitability for *Jatropha*

Agronomic Parameters	Range	Optimal	Kenya (from Survey)		
			Range	Mean	Median
Annual Temperature (°C)	12.7-33.3°C	19.3-27.2°C	16.6-26.7°C	23.2°C	23°C
Annual Rainfall (mm)	440-3,121 mm	1,000-2,000 mm	497-1,976 mm	1,113 mm	1,163 mm
Altitude (m)	0-1,800 m	n/a	0-2,133 m	825 m	736 m
Soil	Well drained, sandy soils w/ pH < 9.[xlvi]		Loamy, sandy.		

The Table also includes the range, mean, and median agronomic characteristics of the *Jatropha* surveyed in Kenya. Compared with the literature, one might expect the typical *Jatropha* farmer in Kenya to be enjoying optimal yields under these conditions. However, based on our empirical survey, not only did we find overall yields to be lower than those discussed in the literature (see Section 4.2.3 below for more on yields), but we also found no significant correlation between yield and growing conditions. As explained further below, the lack of statistical correlation between

Top Left: Red flea beetle mating in Kajiado District, Eastern Province. Top Right: Praying Mantis, a beneficial predator of pests, such as the golden beetle, in Bondo District, Nyanza Province. Bottom Left: Canker caused by an unknown disease in Kilifi District, Coast Province. Bottom Right: Red flea beetle in Nyando District, Nyanza Province.

yield and growing conditions (such as rainfall, elevation, and temperature) means that optimal growing conditions could not be ascertained based on the survey data. A multitude of external factors related to divergent and heterogeneous management practices and inputs makes it extremely difficult to isolate the relationship between agronomic conditions and yields. Dedicated scientific research trials are required to answer these questions.

4.2.2 Pests and Diseases

Some authors claim that few, if any, pests and diseases afflict *Jatropha*. This is generally attributed to the plant's toxicity and insecticidal qualities.[xlvii] These claims have been quite roundly disproven by empirical evidence from the field, which shows that *Jatropha* is susceptible to many pests and diseases.[xlviii] Common pests include: scutellarid bug (*Scutellera nobilis*), inflorescence and capsule-borer (*Pempelia morosalis*), blister miner (*Stomphastis* (*Acrocercops*) *thraustica*), semi looper (*Achaea janata*), flower beetle (*Oxycetonia versicolor*). Termite infestation has also been reported in overage trees. Some diseases reported for *Jatropha* include: root rot (*Clitocybe tabescens*), leaf spot (*Colletotrichum gloeosporioides*), rust (*Phakopsora jatrophicola*), *Cassava* superlongation disease (*Sphaceloma manihoticola/Elsinoe Brasilinesis*). In Zimbabwe and Kenya, powdery mildew damages leaves and flowers, *Alternaria* causes premature leaf fall, and golden flea beetles eat young leaves and shoots. The red and golden flea beetles (*Podagrica spp.*) and "frogeye" fungus (*Cercospera spp.*), which is common in tobacco plants, have been reported.[xlix]

Jatropha farmers in Kenya have reported many pests and diseases. Table 7 lists the most frequent types reported during the field survey. Overall, 63% (169 out of 267) of the *Jatropha* farmers interviewed reported the presence of at least one type of pest (see Table 8). About 14% (39 out of 267) reported two or more different types pests affecting their *Jatropha* plants. Regarding diseases, about 45% (121 out of 267) of farmers reported at least one type of disease, while 16% (43 out of 267) reported two or more diseases.

Table 7: Prevalence of Pests and Diseases Reported on *Jatropha* Farms Surveyed

Pest or Disease Name	Number of Farms Reporting	% of Farms Reporting
Golden Beetle	119	46%
Leaf Spotting	78	29%
Powdery Mildew	58	22%
Red Beetle	47	18%
Fungus	23	9%
Others	54	29%

Table 8: Number of Different Pests and Diseases Reported on Each Farm

Number of Different Pests/Diseases Reported	Pests		Diseases	
	Number of Farms	% of Farms	Number of Farms	% of Farms
0	99	37%	146	55%
1	130	49%	78	29%
2	33	12%	38	14%
3	5	2%	5	2%
Total	267	100%	267	100%

4.2.3 Yields

The economic viability of *Jatropha* seed production is a factor of both input costs and yield, as is explored in depth in Section 4.4 below. The following section provides detailed findings on current *Jatropha* yields in Kenya according to data collected through the field survey. A total of 289 *Jatropha* farms were surveyed, although only a subset of those farms could be used to calculate average yields by year and plantation type. There are various reasons for this, as are explained in detail below.

The limited size of the data pool and the concentration of data points in certain years of growth make it difficult to deduce actual yields for farms three years and older. However, the vast majority of omitted data shows yields even lower than those reported by the included farms, and so anecdotally verify the overall finding of extremely low yields for all age classes and plantation types throughout Kenya.

Another limiting factor for constructing yield curves for the entire period of maturation (which we assume is eight years for *Jatropha*) is the fact that the data was recorded based on observations at one moment in time for each plantation, rather than recorded over a series of years for each plantation. Future research should be geared towards collecting this type of information, as it would provide an even more accurate picture of actual yields over the life of a typical *Jatropha* plantation.

In any survey of this type, we expect to have discrepancies in the data, whether due to communications issues between enumerator and farmer, the lack of proper recordkeeping by farmers, or inaccurate or lacking data entry. The survey was initially designed to limit these problems and to ensure the best quality data possible. For example, farmers were asked to report the quantity of seeds they had "harvested" during the past year, and in a separate question were asked how many kilograms of dried seeds could be obtained from each tree and acre planted. Additionally, the field enumerators randomly selected six trees on each farm, and measured and counted the number of branches and number of fruits per branch on each tree. This provided partial estimates of yielding potentials of seeds per tree, although with obvious limitations due to the fact that different trees in different parts of the country were flowering and fruiting at different times of the year, not necessarily on the particular day we had visited the farm.

Like most statistical analysis of survey information, the compilation of the yield data was complicated by inconsistencies in the raw data. There were several main causes of this. Firstly, six surveys were simply incomplete, so were omitted from the start. Secondly, sixteen additional surveys contained inaccurate yield data due to problems related to errors by one of the enumerators. Once these problems were identified at a small number of sites visited by that enumerator, we independently verified all of the data from sites where data had been collected by the enumerator in question and, from that, determined that sixteen surveys must be removed.

Michael James Mutongolo holding a 60-kilogram bag of Jatropha seeds harvested from three acres of Jatropha planted on his 59-acre farm in Taita District, Coast Province.

Once the data had been entered into the database, we carefully screened and crosschecked it with other, related responses from the questionnaire. We found that some farmers answered, "I did not harvest during the past year," even though it appeared that the trees had produced at least some seed, which for some reason was left uncollected. This phenomenon could have resulted from the lack of a local market for the few seeds produced, a lack of labor available to collect them, or the fact that the *Jatropha* was planted for reasons other than the production of oilseed, such as fencing. Thus as the third type of the data problem, we identified 38 of these missing data cases out of a total of 289 *Jatropha* farms surveyed.

Albert Wamalwa showing some of the 40 kilograms he harvested from the eight *Jatropha* trees (estimated to be eight years old) that he has planted on his eight-acre farm in Bungoma, Western Province.

Forthly, in addition, there were a group of other cases from surveys taken throughout the outgrower scheme at Shimba Hills where reported yields were significantly lower than the national average. This was either the result of actual below-average yields due to poor agronomic conditions or management practices, or from a systematic underestimation of seed production for many of the same reasons given in the previous paragraph. However, the presence of the company supporting the outgrower scheme, Energy Africa Ltd. (EA), suggests an available market for seeds unlike many other parts of rural Kenya. A close look at the data, as well as discussions with farmers, extension officers, and EA officials, all point to significantly lower actual yields than systematic underestimation as the reason for lower reported yields from these Shimba Hills cases.

The Shimba Hills cases include 75 of the 289 (26%) *Jatropha* farms visited during the field survey. The vast majority of those cases involved plantations that were established three years before the survey, and thus tend to distort the national averages for three-year-old plantations. Combined with the missing data cases discussed above, the low-yield Shimba Hills cases have a significant down-weighting effect on the general yield trends, especially in the third year. Thus, we decided to exclude 75 Shimba Hills cases along with the 38 missing data cases described above, or 109 cases combined, to calculate the national yield average (four of the Shimba Hills cases were overlapping with missing data cases).

Once the twenty-two incomplete and inaccurate surveys were removed along with the 109 Shimba Hills and missing data cases, the final task in cleaning the data was dealing with remaining statistical outliers. We dealt with this first by creating a statistical model to estimate the predictable trend of the observed data. For example, if yield is expressed as a function of certain variables – such as age, agro-climatic zone, and plantation type – outliers are identified by comparing actual yields with predicted yields from the model. An analysis of variance, or ANOVA, was used to test which categorical variable in the estimated model had significant affects on yields. While ANOVA assumes that the data is distributed normally, the data was highly skewed due to the preponderance of data points at or close to zero, meaning reports of no yield. We then applied square root and cubic root power transformations to reduce variation and normalize the data. However, the transformed data still did not improve the fit of the model when tested with ANOVA and the Akaike Information Criterion, which is a method of evaluating the degree of fit between models.

We next attempted to weight the yield by standard deviation as a way of downweighting the variance in the data. Again, the weighted data did not improve the fit of the model. Thus, we decided to use the original cleaned data. Another ANOVA test found that only age group and plantation type, but not agro-climatic zone, were significantly correlated among the three independent categorical variables.

In the next step, we tried to identify and remove outliers, or cases with abnormally high yields for particular age group or plantation type categories, by using the Restricted Maximum Likelihood (REML) estimation method. REML can produce unbiased estimates of variance and covariance parameters. Once residuals for each case were computed, a studentized residual was derived by dividing each residual by an estimate of its standard deviation. We identified and excluded 15 more cases as outliers. These included the following cases of extremely high yields: a farm with an eight year-old fence in Bungoma West, Western Province with the reported yield of 5kg/tree (a studentized residual of 11.3984) (see photos to the left); a 35 year-old fence in Taita, Coastal Province with the reported yield of 2.67kg/tree (4.024); a 2 year-old, 0.03 acre plot in Central Province with a reported yield of 1.67kg/tree (3.9384). We also removed cases reporting zero yield for plantations older than three years.

By removing these outliers, we do not necessarily discount that the data of age and yield are accurate. However, they are highly atypical of the vast majority of farmers' experiences throughout the country, so cannot reflect an accurate measure of the mean and median yields for their age classes. The cases should be studied by research scientists to determine whether the particular genetic material of the seed germplasm, the management practices, agro-climatic conditions, or some combination of these factors led to the much higher yields than seen elsewhere.

Table 9: Observed *Jatropha* Yields by Plantation Type and Age (kilograms per tree)

Monoculture	Farms	Mean	Median	Minimum	Maximum
Year 1	13 (46%)	0.004	0.000	0.000	0.050
Year 2	7 (25%)	0.085	0.059	0.000	0.238
Year 3	5 (18%)	0.063	0.050	0.002	0.185
Year 4	2 (7%)	0.016	0.016	0.013	0.020
Years 5+	1 (4%)	0.800	0.800	0.800	0.800
Intercrop	Farms	Mean	Median	Minimum	Maximum
Year 1	36 (49%)	0.002	0.000	0.000	0.067
Year 2	18 (25%)	0.079	0.010	0.000	0.500
Year 3	8 (11%)	0.015	0.008	0.001	0.067

Year 4	6 (8%)	0.428	0.212	0.011	1.000
Years 5+	5 (7%)	0.202	0.160	0.040	0.375
Fence	Farms	Mean	Median	Minimum	Maximum
Year 1	9 (21%)	0.002	0.000	0.000	0.017
Year 2	7 (17%)	0.036	0.010	0.001	0.121
Year 3	3 (7%)	0.059	0.050	0.007	0.120
Year 4	2 (5%)	0.100	0.100	0.067	0.133
Years 5+	21 (50%)	0.535	0.267	0.016	2.000
Total	Farms	Mean	Median	Minimum	Maximum
Year 1	58 (41%)	0.003	0.000	0.000	0.067
Year 2	32 (22%)	0.071	0.011	0.000	0.500
Year 3	16 (11%)	0.038	0.015	0.001	0.185
Year 4	10 (7%)	0.296	0.133	0.011	1.000
Years 5+	27 (19%)	0.483	0.267	0.016	2.000

In summary, we removed a total of 146 cases out of a total of 289 farms surveyed. The remaining 143 cases were then analyzed according to plantation age and type, as shown in Table 9. All plantation types show close to zero yield for one-year-old plantations. Yields show incremental growth in the second year, but then decline in the third year for both monoculture and intercrop plantations. However, this decline may not be statistically significant because of the size of the data pool. Over seventy percent of all yield data points for monoculture and intercropped plantations come from farms with *Jatropha* two years or younger. As far as the low third-year yields may accurately portray what is happening more broadly among farms with plantations that age, one possible explanation for the low yields is that farmers may have become disenchanted with the crop after three years and begun neglecting it.

The yield curve for fence plantations may be more predictive of actual yields over the full period of maturation. Fifty percent of the fence plantations surveyed were over five years old. The average age of these plantations was nearly 13 years old and the median age about 10 years old. Thus, the reported average yield of nearly 0.5 kilograms per tree for fence plantations over five years may be accurate, but represents yields from trees that are quite mature.

The limited amount of data available, especially for plantations three years and older for monoculture and intercropped plantations required us to estimate growth after year two. We used two scenarios to do this. The first, or "low" scenario simply continues the same rate of growth observed during the first two years, while the second, or "high" scenario, applies the rate of growth predicted by Dr D.N. Tewari, a member of India's Planning Commission and an ICRAF Board Member, based on reports of *Jatropha* growing in marginal lands in India.[1] Chart 7 and Table 10 show the results graphically and tabularly.

Monoculture plantations show the highest rate of growth in terms of yield, followed by intercropped and then fence plantation types. This is likely due to management practices and inputs being greatest for monoculture given the fact that the farmer has chosen to dedicate land solely for *Jatropha*. Yields may continue to increase annually after the eighth year, as is indicated by the nearly 0.5 kilograms per tree average yield for fence plantations over 10 years old.

Chart 7: Observed and Projected *Jatropha* Yields by Plantation Type and Age

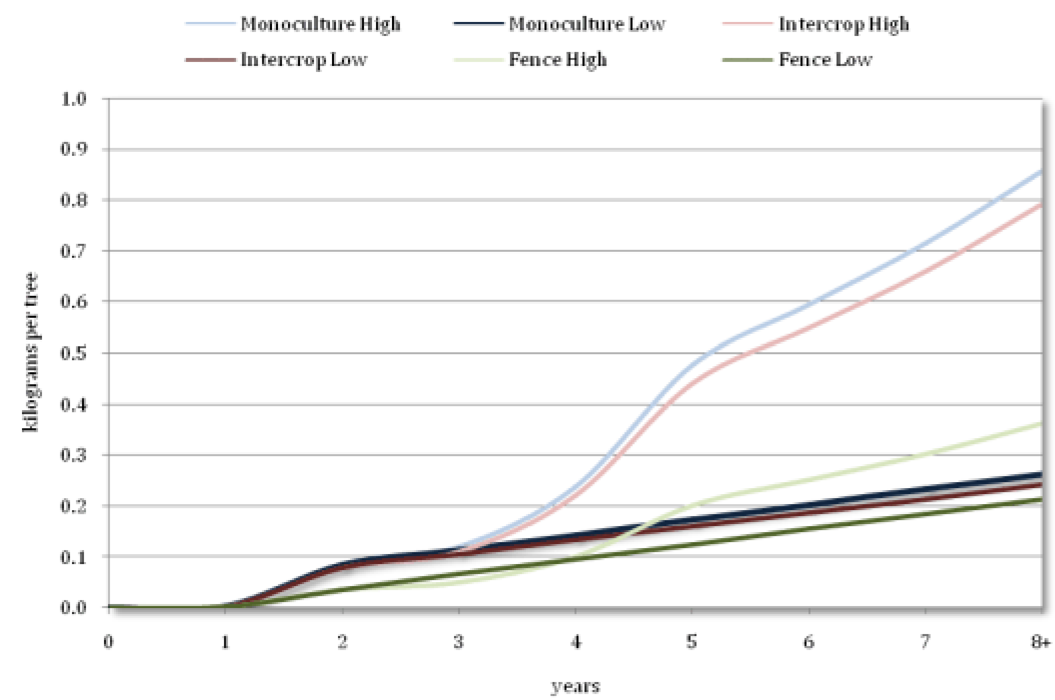


Table 10: Observed & Projected *Jatropha* Yields by Plantation Type and Age (kilograms per tree)

	Monoculture			Intercrop			Fence		
	Actual	Low	High	Actual	Low	High	Actual	Low	High
Year 0	0			0			0		
Year 1	0.004			0.002			0.002		
Year 2	0.085			0.079			0.036		
Year 3	0.063	0.115	0.119	0.015	0.106	0.110	0.059	0.066	0.050
Year 4	0.016	0.144	0.238	0.428	0.133	0.220	0.100	0.095	0.100
Year 5	0.800	0.174	0.476	0.202	0.160	0.440	0.535	0.125	0.200
Year 6		0.204	0.595		0.187	0.550		0.155	0.251
Year 7		0.234	0.714		0.214	0.660		0.184	0.301
Year 8+		0.263	0.857		0.241	0.793		0.214	0.361

Yields reported in the literature from around the world are significantly higher than those found in Kenya. In order to compare reported yields to those in Kenya, we averaged the yields per tree that were available from the literature for each age class (see Table 11). The variability of reported yields is underscored by the uneven growth curve from year zero through eight, but nonetheless shows a trend, which we have mapped in Chart 8. We did not include any unsubstantiated reported yields from undocumented sources, which are typically even higher than the ones included here.

Table 11: Reported *Jatropha* Yields from Global Literature Search								
Country	Year 1	2	3	4	5	6	7	8+
Burkina Faso[li]								0.96
Cape Verde[lii]								0.32
Cape Verde[liii]								0.81
Guatemala[liv]		0.81						
India[lv]		1.12						
India[lvi]			0.20					
India[lvii]			0.76					
India[lviii]		0.82						
Indonesia[lix]								2.91
Mali[lx]		0.22						
Mali[lxi]								1.94
Mali[lxii]								1.71
Mali[lxiii]								5.18
Nicaragua[lxiv]		1.50	1.80	2.25				
Nicaragua[lxv]					3.24			
Paraguay[lxvi]			0.06	0.45	0.65	1.29	1.94	2.59
Tanzania[lxvii]	0.00	0.00	0.23					
Tanzania[lxviii]			0.50					
Thailand[lxix]		0.51						
Zimbabwe[lxx]								0.40

Chart 8: Average Global Yields vs. Kenyan Yields

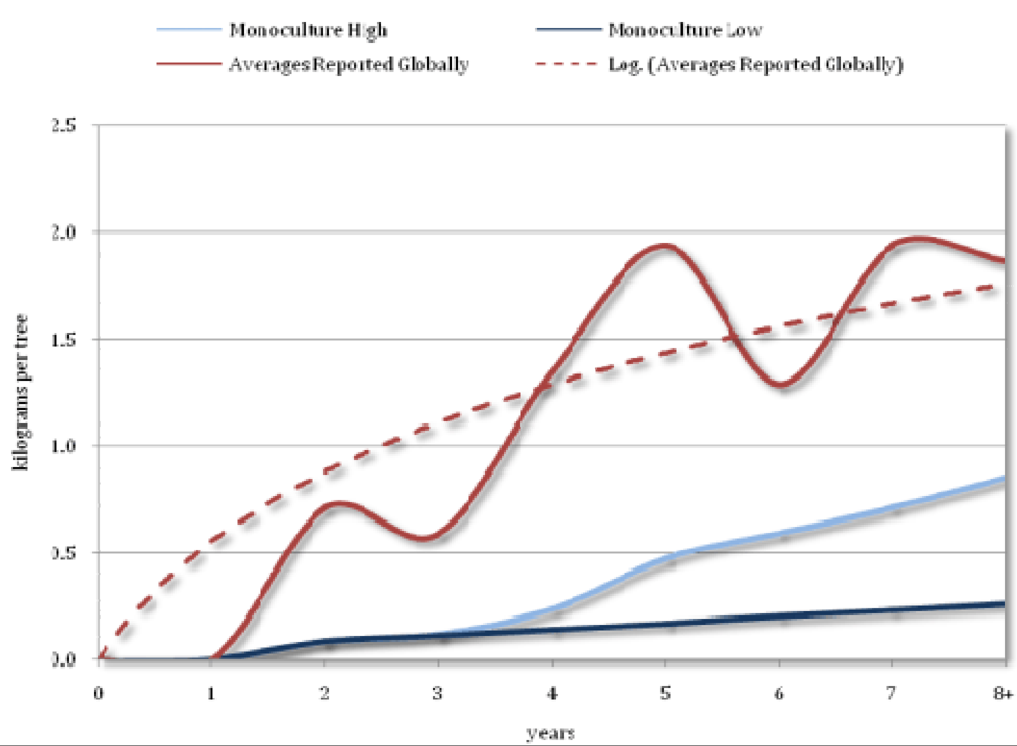


Chart 8 and Table 12 compare the average yields reported globally to yields found in Kenya on monoculture plantations, which were the highest of all plantation types. The average yield globally over eight years is 1.214 kilograms per tree compared with 0.386 and 0.153 kilograms per tree for the high and low case scenario monoculture plantations in Kenya. In other words, the average yield as reported in the literature from around the world is between 3.8 and 8.0 times the amounts reported in Kenya.

Table 12: Magnitude Difference Between Average Global Yields vs. Kenyan Yields

Type	1	2	3	4	5	6	7	8+	Avg.
Averages Reported Globally	0.000	0.714	0.594	1.354	1.944	1.294	1.942	1.870	1.214
Monoculture High	0.004	0.085	0.119	0.238	0.476	0.595	0.714	0.857	0.386
Magnitude Difference (times greater)	0 x	8.4 x	5.0 x	5.7 x	4.1 x	2.2 x	2.7 x	2.2 x	3.8 x
Monoculture Low	0.004	0.085	0.115	0.144	0.174	0.204	0.234	0.263	0.153
Magnitude Difference (times greater)	0 x	8.4 x	5.2 x	9.4 x	11.2 x	6.3 x	8.3 x	7.1 x	8.0 x

When considering reported yields from around the world, it is important to note that very little data has been collected to date regarding yields in semi-arid to transitional regions in sub-Saharan Africa. However, the little empirical data that does exist from locations similar to Kenya seem to support the findings of low yields from the Kenya survey. For example, a large-scale monoculture plantation in the Arusha region of the northern Tanzania reported relatively low yields of about 0.5 kilograms per tree despite the application of fertilizers, pesticides, and frequent irrigation.[lxxi] Another large plantation in the same area simply abandoned operations due to disappointing results.[lxxii]

In the more arid Mpanda region of western Tanzania, a German company called Prokon started contract farming *Jatropha* with approximately 16,800 farmers in 2005-2006. A recent survey of 129 of their farmers with three year-old plantations found a rather dismal state of affairs.[lxxiii] In the first season of cultivation, only five farmers had yields larger then a hand full (0.004-0.008 kilograms per tree), while the large majority (96.95%) had no yield at all, resulting in an average yield of 0.0002 kilograms per tree. In the second season, seeds were only collected in one village with an average yield of 0.0008 kilograms per tree. The average yield for the third season was 0.23 kilograms per tree. These actual results were far lower than the projection by a Prokon agronomist of 4-9 kilograms per tree.

Even in India, where the government is pushing to plant over 33.1 million acresof *Jatropha*, recent reports are not very encouraging. A model farm established in 2005 by a researcher in the Vyasa district of India's Northern State of Gujarat has produced a mere 0.2 kilograms per tree in the fourth year.[lxxiv] In the more fertile areas of the Assam State, D1 Oils initiated a *Jatropha* plantation in 2006 with the expectation of 3.3 tonnes per acre, or 5.28 kilograms per tree at 2.5 by 2.5 meter spacing, from an improved variety, and 2.1 tonnes per acre, or 3.36 kilograms per tree, from normal seed.[lxxv] After two years, they were still struggling to achieve 0.476 tonnes per acre, or 0.76 kilograms per tree from the improved variety.[lxxvi]

The current conclusion, based on these experiences and those observed as part of this study, is that *Jatropha* is not a wasteland crop. It needs fertilizer, water, and good management. And even then, results are unpredictable. It is difficult to establish a relationship between yield and agro-climatic zone or site conditions. Most reports on *Jatropha* seed yields do not distinguish what variables are believed to have most influenced yields. Part of the reason for this is the lack of scientific research trials that can isolate different factors over multiple years to discern the relevant significance of each on yield.

4.2.4 Treatment and Management

Notwithstanding evidence of low yields from the field, some claim that *Jatropha* can be grown as a plantation crop in areas of low rainfall and in nutrient-poor soils.[lxxvii] Thus, it is often inferred that *Jatropha* may have low water, nutrient, and other input requirements.[lxxviii] But, as the previous section shows, and as many farmers in Kenya have found, the contrary appears to be true. Indeed, a recent study found that *Jatropha* requires about 40% more water than *Rapeseed* and *Soy* to produce an equivalent amount of oil, although some experts have called the study's methodologies into question.[lxxix] Initial lessons also indicate that fertilizer is needed to get reasonable yields, pests and diseases are a major challenge, and weeding and harvesting is labor-intensive due to heterogeneous fruiting.[lxxx]

Growing and managing *Jatropha* productively is poorly documented scientifically, while anecdotes assuming low input requirements circulate on the Internet and among some opportunistic *Jatropha* promoters.[lxxxi] Relying on such information, many farmers started planting *Jatropha* with minimal inputs and labor, but soon realized that it is actually vulnerable to drought and prone to pests and diseases, among other issues. *Jatropha* plantations likely require management and treatment similar to high value crops like coffee, tea, or citrus, not only to ensure high plant growth but also to maximize yields through optimum spacing, weeding, pruning, and branching.

Propagation and Spacing

Jatropha may be propagated by direct seeding, pre-cultivation of seedlings, or transplantation of cuttings. Compared with cuttings, plants propagated by seeds or seedlings will develop deep taproots, and thus are thought to be preferred for oil production due to their ability to have more access to nutrients and moisture from deeper soil layers. Cuttings have been promoted due to the shortened period before the first harvest, compared with seedlings and direct sowing. Cuttings are also commonly used for fencing. About 45% of the *Jatropha* farmers interviewed in this study used direct sowing of seeds, 31% used seedlings, and 19% cuttings (see Chart 9).

Some researchers indicate, that aiming mainly at oil production, large scale monoculture block plantations may be the best option.[lxxxii] While closer spacing allows more trees to be planted per acre, wider spacing may be required in arid regions to ensure no competition between roots for water and nutrients. It has been suggested that wider spacing (at least 3 by 3 meters, or 450 trees per acre) should be used in semi-arid environments, while denser plantations (2 by 2 meters, or 1,000 trees per acre; or 2.5 by 2.5 meters, or 650 trees per acre) may be appropriate for sub-humid areas.[lxxxiii] When planting for fencing or to prevent erosion, a denser spacing of 1 meter or less may be appropriate.[lxxxiv] Over 40% of the farmers interviewed as part of this survey had planted their *Jatropha* with 2 by 2 meter spacing. The next most common spacing used was 3 by 3 meters, with over 14%.

Seed Varieties and Sources

No clearly defined *Jatropha* provenances exist yet in Kenya, although KEFRI has tentatively classified four sources: Coast, Kitui, Kajiado and Maseno.[lxxxv] Chart 10 shows the diverse sources of planting materials used by Kenyan *Jatropha* farmers. Seeds obtained in Central Province are mainly from either nurseries in Embu, or wild seeds collected from trees in Muranga South and North Districts. Planting materials from Coast Province are mainly from seeds or cuttings of wild local trees. Seeds from Rift Valley are mainly from Nguruman, south of Lake Magadi. For Nairobi sourced materials, farmers referred to the nurseries or individuals in Nairobi from whom they bought seeds, but it is likely the real sources were elsewhere. Materials originating in Tanzania are mostly from Kakute, an Arusha-based company. One private company in Central Province and one international NGO procured seeds from India. Materials from unknown sources were obtained from neighbors, NGOs, agricultural officers and even Chinese road constructors (a few farmers in Keiyo District, Rift Valley), but with no knowledge of the original source.

Chart 9: Propagation Methods of *Jatropha* Farms

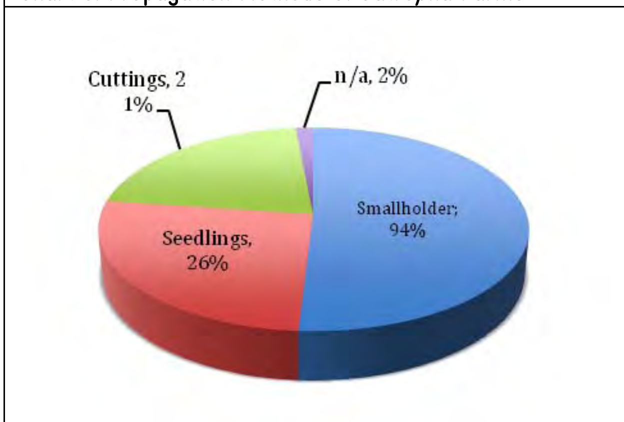
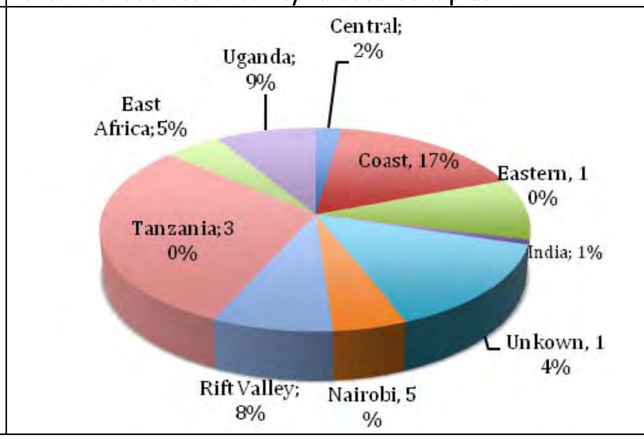


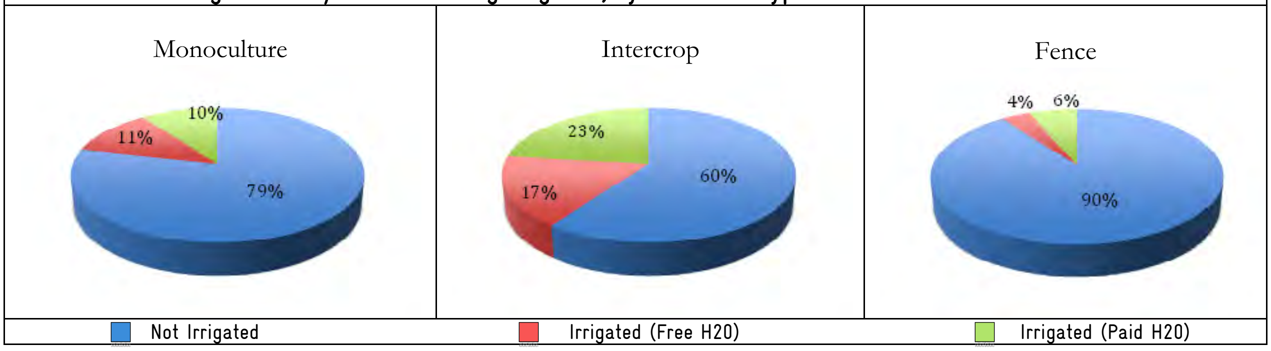
Chart 10: Sources of *Jatropha* Seed Germplasm



Irrigation

The majority of *Jatropha* farmers surveyed do not use irrigation (see Chart 11 below). About 40% of farmers growing intercropped *Jatropha* used some form of irrigation, while 21% of monoculture plantations and 10% of fences do. Most of those who do irrigate their *Jatropha* use a free source of water. Those who applied irrigation watered for some duration just after the planting or for the spell of dry seasons to ensure the survival of the seeds, seedlings, or cuttings. Among all plantation types, 14% irrigated only at the time of planting only, while 16% occasionally applied irrigation even after the period of planting.

Chart 11: Percentage of *Jatropha* Farms Using Irrigation, by Plantation Type

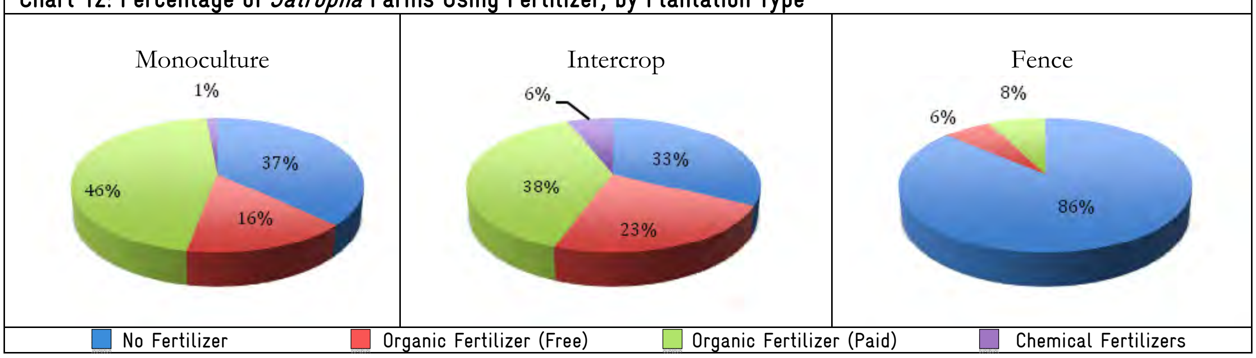


Fertilization

As with any crop, irrigation and fertilizer (inorganic or organic) requirements depend on the climatic and soil conditions of the location. Simultaneous reclamation of barren lands and biodiesel production will inevitably imply use of fertilizer and irrigation.[lxxxvi] Indeed, it is claimed that fertilizer is essential to ensure higher yields for commercial production even in agriculturally favorable areas.[lxxxvii]

Chart 12 presents the fertilizer application by plantation type. For all the plantation types combined, about 50% of the total farmers surveyed applied fertilizer of some type, mostly in the form of paid organic fertilizer (30%) and free organic fertilizer (20%). Monoculture and intercrop farms were more likely than fenced ones to use fertilizer. Very few farmers used chemical fertilizers, but the proportion of chemical fertilizer application was slightly higher for intercropped than for monoculture farms.

Chart 12: Percentage of *Jatropha* Farms Using Fertilizer, by Plantation Type



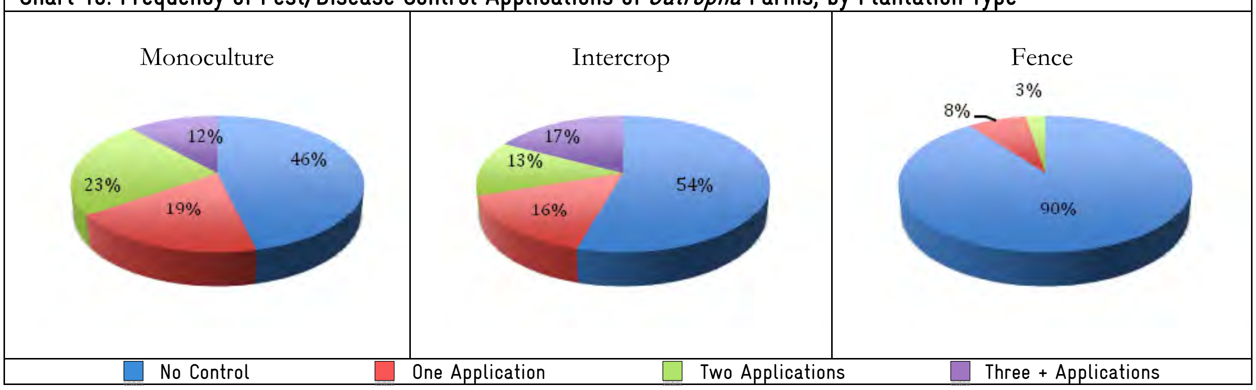
The average amount of organic (manure or compost) fertilizer – the most common fertilizer – used by all farms was 1,871 grams per tree (see Table 13). Intercropped farms applied more organic fertilizer than monoculture and fenced farms, although the mean for fence is higher due to some extremely high amounts given by the small number of fence farmers who used fertilizer. The average price paid for organic fertilizer was Ksh 1.1 per kilogram. Farmers who used chemical fertilizers applied an average of 235 grams per tree, although the median amount was much lower at 5 grams per tree, which is likely the more typical amount used. The unit price for chemical fertilizer was Ksh 60 per kilogram. Overall, very few person days per year were allocated for fertilizer application, and proportionally more farmers applied family labor for fertilizer application than hired labor.

Table 13: Amount of Organic Fertilizer (Manure) Used by *Jatropha* Farms, by Plantation Type								
Organic Fertilizer (grams/tree)	Monoculture		Intercrop		Fence		Total	
	Total	Applied	Total	Applied	Total	Applied	Total	Applied
Number Farms	69	43	114	75	76	11	259	129
Mean	822	1,320	1,329	2,019	437	3,018	932	1,871
Median	500	500	500	1,000	0	1,000	0	1,000

Pest and Disease Control

As indicated above, pests and diseases have been reported to affect a majority of *Jatropha* farms surveyed. Nonetheless, resource limitations or a lack of education, or both, have led to the majority of *Jatropha* farmers being incapable of adequately dealing with the pests and diseases affecting their farms. As indicated in Chart 13 below, over half of the monoculture plantations surveyed applied a pest or disease control at least one time during the previous year, while less than half of intercropped farms did, and only 11% of fence farms.

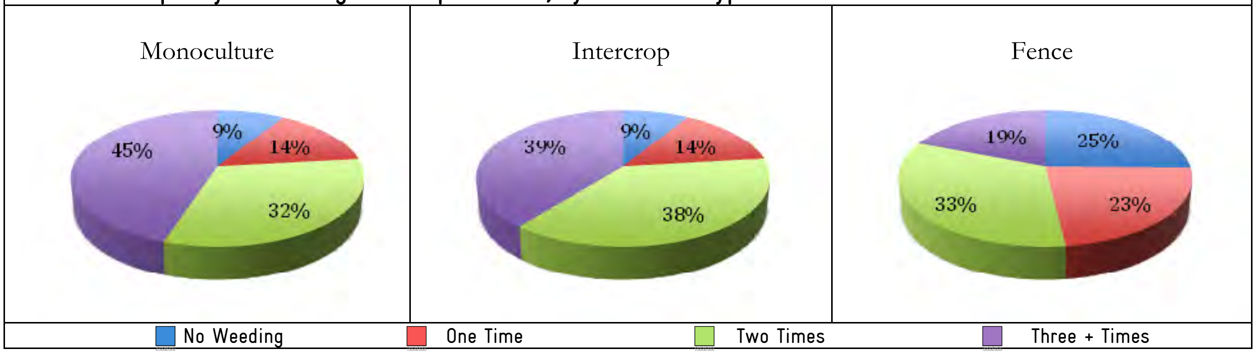
Chart 13: Frequency of Pest/Disease Control Applications of *Jatropha* Farms, by Plantation Type



Weeding and Pruning

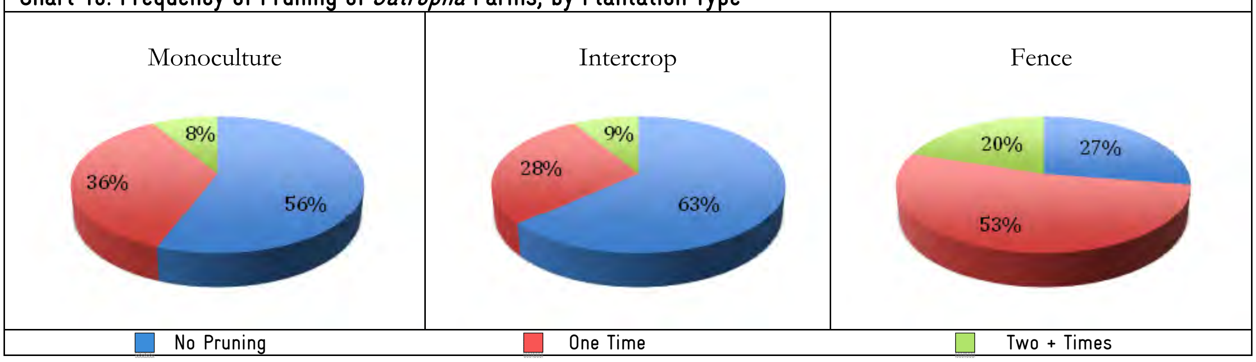
Weeding is important to ensure no competition for water and nutrients. About 86% of farmers surveyed conducted at least one weeding per year, with a majority doing two or more (see Chart 14). Nearly 90% of the monoculture and intercrop farms weeded at least once during the past year, while 75% of the fence farmers did.

Chart 14: Frequency of Weeding of Jatropha Farms, by Plantation Type



As *Jatropha* is a terminal-flower-bearing plant, pruning is critical to increasing the number of branches and terminals capable of producing fruits. Pruning and weeding are reported to have affected growth performance in western Tanzania.[lxxxviii] Chart 15 shows the frequency of pruning by plantation type. Less than 50% of all farms pruned in the year prior to the survey, while about 30% pruned one time. Fence plantations were pruned more regularly than monoculture and intercropped ones. About 56% of the monoculture plantations and 63% of the intercropped ones never pruned.

Chart 15: Frequency of Pruning of *Jatropha* Farms, by Plantation Type



4.3 Economics

4.3.1 Cost of Production

As with any crop, the economic viability of *Jatropha* seed production is a factor of production cost, yield, and market price. This section presents a cost-benefit analysis for a model one-acre smallholder farm, based on costs, yield, and market prices from the survey. The analysis contains the three plantation types commonly found in Kenya and other parts of the developing world: monoculture, intercrop, and fence. Each scenario is modeled with both low and high yields, based on average yields in Kenya for each plantation type (see Section 4.2.3 above for more information on how we estimated yields).

Jatropha SVO sample.

Tables 14 through 16 provide a breakdown of the input and labor costs for each plantation type over a 10-year period. The monoculture plantation contains 647 trees spaced 2.5 by 2.5 meters apart, which requires about one kilogram of seeds as planting material. The intercrop plantation contains 253 trees spaced 4 by 4 meters, requiring 0.4 kilograms of seeds. The fence plantation contains 508 trees spaced along the border 0.5 meters apart, requiring 0.9 kilograms of seeds. The cost of seeds is Ksh 775 per kilogram, which is the average price paid by farmers throughout Kenya, according to the survey.

Planting and establishment equipment includes rope and stakes for laying out the spacing in the plantation, hoes/ jembes (jembes are also hoes), and pangas (machetes) for clearing land, cutting weeds, and digging holes. Land preparation, planting, pruning, and weeding equipment costs are the median amount paid by farmers surveyed for each plantation type. Organic fertilizer, or manure, costs are based on the average quantities per treatment times the number of treatments currently being given by the average farmer in Kenya. For example, 78 of 130 farmers surveyed with intercropped *Jatropha* used manure as fertilizer. An average of 1.2 kilograms was applied per treatment with an average of 1.44 treatments per year. A kilogram of manure costs an average of Ksh 1.1. No manure costs were included for the fence plantation due to the fact that only 17% of farmers growing *Jatropha* fences used fertilizer.

Similarly, the costs for pest and disease control are based on the average costs reported by farmers within each plantation type. As very few farmers with fence plantations use any type of pest and disease control, no cost is assumed for the fence budget. Harvesting and seed processing equipment includes buckets, tarps, and 60-kilogram bags, and is based on the amount required for the predicted yields.

Labor costs include the number of person/days per year of paid labor for each plantation type based on the average reported by the farmers included in the survey. The average daily wage is Ksh 164 per day, and is also based on the average wage paid by farmers interviewed. Family labor, although significant, is not included in the budgets. As you can see in Table 16, no paid labor is included for the fence plantation, as was found to be the predominant case with farmers growing fence plantations in Kenya.

Table 14: Cost of Production Over 10 Years, One-Acre Monoculture *Jatropha* Plantation										
Year	0	1	2	3	4	5	6	7	8	9	Totals
Inputs (Ksh/acre)											
Seeds	775	0	0	0	0	0	0	0	0	0	775
Land Prep/Plant Equip	800	0	0	0	0	0	0	0	0	0	800
Weeding/Pruning Equip	450	45	45	45	45	45	45	45	45	45	855
Manure	1,245	1,245	1,245	1,245	1,245	1,245	1,245	1,245	1,245	1,245	12,452
Pest/Disease Control	3,661	3,661	3,661	3,661	3,661	3,661	3,661	3,661	3,661	3,661	36,608
Harvesting Equipment	0	500	50	50	500	50	50	50	50	50	1,350
Seed Processing/Storage	20	1,040	60	80	100	120	140	160	160	160	2,040
Inputs Sub-Total	6,951	6,491	5,061	5,081	5,551	5,121	5,141	5,161	5,161	5,161	54,880
Labor (Ksh/acre)											
Land Preparation	1,037	0	0	0	0	0	0	0	0	0	1,037
Planting	891	0	0	0	0	0	0	0	0	0	891
Fertilization	243	243	243	243	243	243	243	243	243	243	2,425
Pest Disease Mgmt.	208	208	208	208	208	208	208	208	208	208	2,081
Weeding	983	983	983	983	983	983	983	983	983	983	9,833
Harvesting	0	656	983	1,639	1,639	1,639	2,622	2,622	2,622	2,622	17,043
Labor Sub-Total	3,363	2,089	2,417	3,073	3,073	3,073	4,056	4,056	4,056	4,056	33,311
Cost Total	10,314	8,580	7,478	8,154	8,624	8,194	9,197	9,217	9,217	9,217	88,191

Table 15: Cost of Production Over 10 Years, One-Acre Intercrop *Jatropha* Plantation										
Year	0	1	2	3	4	5	6	7	8	9	Totals
Inputs (Ksh/acre)											
Seeds	310	0	0	0	0	0	0	0	0	0	310
Land Prep/Plant Equip	550	0	0	0	0	0	0	0	0	0	550
Weeding/Pruning Equip	400	40	40	40	40	40	40	40	40	40	760
Manure	492	492	492	492	492	492	492	492	492	492	4,917
Pest/Disease Control	1,997	1,997	1,997	1,997	1,997	1,997	1,997	1,997	1,997	1,997	19,968
Harvesting Equipment	0	500	50	50	500	50	50	50	50	50	1,350
Seed Processing/Storage	20	40	1,040	40	40	60	60	80	80	80	1,540
Inputs Sub-Total	3,769	3,069	3,619	2,619	3,069	2,639	2,639	2,659	2,659	2,659	29,395
Labor (Ksh/acre)											
Land Preparation	688	0	0	0	0	0	0	0	0	0	688
Planting	873	0	0	0	0	0	0	0	0	0	873
Fertilization	229	229	229	229	229	229	229	229	229	229	2,294
Pest Disease Mgmt.	126	126	126	126	126	126	126	126	126	126	1,262
Weeding	492	492	492	492	492	492	492	492	492	492	4,916
Harvesting	0	492	819	1,311	1,311	1,311	1,967	1,967	1,967	1,967	13,110
Labor Sub-Total	2,409	1,339	1,667	2,158	2,158	2,158	2,814	2,814	2,814	2,814	23,144
Cost Total	6,177	4,407	5,285	4,777	5,227	4,797	5,452	5,472	5,472	5,472	52,539

Table 16: Cost of Production Over 10 Years, One-Acre Fence *Jatropha* Plantation										
Cost of Production	0	1	2	3	4	5	6	7	8	9	Totals
Inputs (Ksh/acre)											
Seeds	698	0	0	0	0	0	0	0	0	0	698
Land Prep/Plant Equip	500	0	0	0	0	0	0	0	0	0	500
Weeding/Pruning Equip	400	40	40	40	40	40	40	40	40	40	760
Manure	0	0	0	0	0	0	0	0	0	0	0
Pest/Disease Control	0	0	0	0	0	0	0	0	0	0	0
Harvesting Equipment	0	500	50	50	50	50	50	50	50	50	900
Seed Processing/Storage	20	20	1,020	40	60	80	80	100	100	100	1,620
Inputs Sub-Total	1,618	560	1,110	130	150	170	170	190	190	190	4,478
Labor (Ksh/acre)											
Land Preparation	0	0	0	0	0	0	0	0	0	0	0
Planting	0	0	0	0	0	0	0	0	0	0	0
Fertilization	0	0	0	0	0	0	0	0	0	0	0
Pest Disease Mgmt.	0	0	0	0	0	0	0	0	0	0	0
Weeding	0	0	0	0	0	0	0	0	0	0	0
Harvesting	0	0	0	0	0	0	0	0	0	0	0
Labor Sub-Total	0	0	0	0	0	0	0	0	0	0	0
Cost Total	1,618	560	1,110	130	150	170	170	190	190	190	4,478

Not surprisingly, the cost of production is highest for monoculture and lowest for fence plantations. However, yields are also highest for monoculture and lowest for fence, as is discussed more in Section 4.2.3 on yields, and in the following section. The fundamental question is whether the added costs are justified by the relative benefits of each plantation type.

4.3.2 Prices, Markets and Revenue

Over the past few years, farmers and investors have rushed to plant *Jatropha* with visions of tremendous gains fed by hype-inducing promoters with little practical experience. Although far below expectations, many of these farmers have begun harvesting small quantities of seeds from their relatively young plantations. However, the market has not materialized as expected. The problem is twofold. First, the quantities and geographic distribution of seed production are so small and scattered that buyers are either unavailable or too expensive to access. Second, the prices being offered are well below the expectations of many farmers.

The price of seed for biodiesel or SVO is pegged to the price of diesel. Surprisingly, we found that few farmers were aware of the connection between the two, or had thought much about what that would amount to for a kilogram or tonne of seed that they might produce. Many farmers had their expectations set very high by the promoters they had originally bought seeds from, or from one-time foreign buyers. As we learned speaking to farmers, many expected to be able to sell their seeds for around the same price they had purchased them for, an average of about Ksh 775 per kilogram. However, a marketable price for producing biodiesel is roughly Ksh 10-15 per kilogram, assuming about four kilograms of seed is required for one liter of oil and the current price of diesel ranges between Ksh 60-80 per liter. Many farmers were shocked to hear that the market for seeds would fetch such low prices.

Tables 17 through 19 show the expected revenue for each plantation type based on a price of Ksh 15 per kilogram. The yields are based on the averages reported by farmers throughout Kenya for the first three years and are discussed in depth in Section 4.2.3 above. Yields for years three through nine are projected based on low and high scenarios. The low scenario simply continues the rate of growth reported for the first five years, while the high scenario projects a rate of growth based on reported in the scientific literature.

Table 17: Revenue Over 10 Years, One-Acre Monoculture *Jatropha* Plantation

Years	0	1	2	3	4	5	6	7	8	9	Totals
Yield Low (kg/acre)	0	3	55	74	93	113	132	151	170	170	961
Yield Hi (kg/acre)	0	3	55	77	154	308	385	462	554	554	2,552
Farm Price (Ksh/kg)	15	15	15	15	15	15	15	15	15	15	15
Revenue Low Total	0	39	825	1,116	1,398	1,689	1,980	2,271	2,552	2,552	14,422
Revenue Hi Total	0	39	825	1,155	2,310	4,620	5,774	6,929	8,317	8,317	38,286

Table 18: Revenue Over 10 Years, One-Acre Intercrop *Jatropha* Plantation

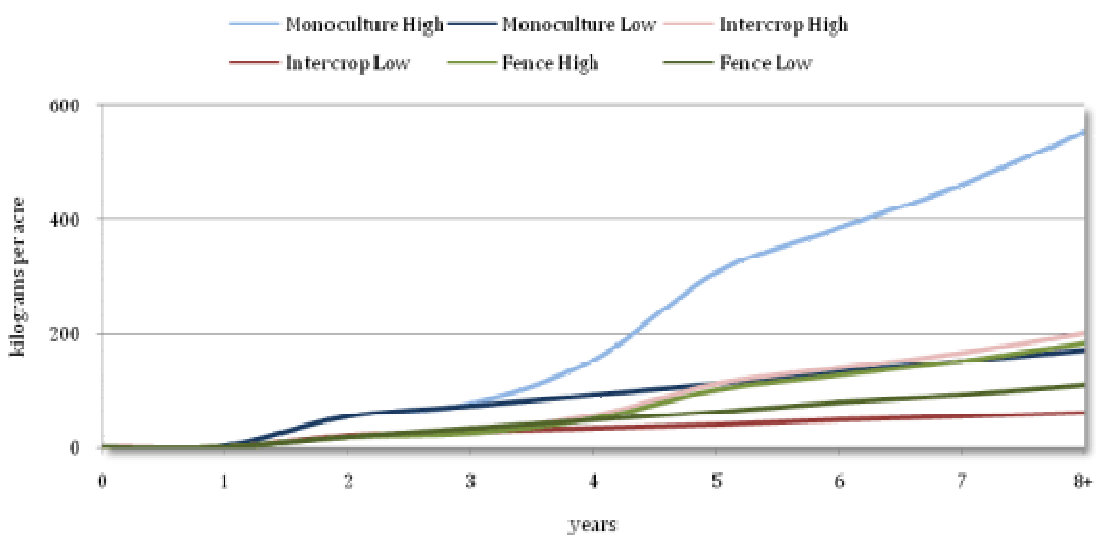
Years	0	1	2	3	4	5	6	7	8	9	Totals
Yield Low (kg/acre)	0	1	20	27	34	40	47	54	61	61	345
Yield Hi (kg/acre)	0	1	20	28	56	111	139	167	201	201	923
Farm Price (Ksh/kg)	15	15	15	15	15	15	15	15	15	15	15
Revenue Low Total	0	8	300	402	505	607	710	812	915	915	5,173
Revenue Hi Total	0	8	300	417	835	1,670	2,087	2,505	3,009	3,009	13,840

Table 19: Cost of Production Over 10 Years, One-Acre Fence *Jatropha* Plantation

Years	0	1	2	3	4	5	6	7	8	9	Totals
Yield Low (kg/acre)	0	1	18	34	48	64	79	93	109	109	554
Yield Hi (kg/acre)	0	1	18	25	51	102	128	153	183	183	844
Farm Price (Ksh/kg)	15	15	15	15	15	15	15	15	15	15	15
Revenue Low Total	0	15	274	503	724	953	1,181	1,402	1,631	1,631	8,313
Revenue Hi Total	0	15	274	381	762	1,524	1,913	2,294	2,751	2,751	12,664

Chart 16 overlays the projected yields for each plantation type based on an acre of land spaced according to the models being evaluated. Interestingly, the per acre yield for intercrop and fence plantations are nearly similar. The lower yield per tree that is reported for fence plantations throughout Kenya is balanced out by the greater number of trees per acre, compared with the intercrop plantation model. This is significant given the large difference in input costs between the two plantation types.

Chart 16: Actual (Years 0-5) and Projected (Years 6+) *Jatropha* Yields per Acre, by Plantation Type



4.3.3 Net Margins, Break-Even Analysis and Internal Rates of Return

The fundamental measure of whether the crop should be promoted must begin with whether smallholder farmers can reap a net benefit from choosing to grow *Jatropha* over other crops, such as maize and beans. The analysis contained in this report is based on the actual costs and yields of the farmers interviewed as part of the field survey.

Considering the amount of attention *Jatropha* has received, the results of our analysis for smallholder Jatropha farming in Kenya are quite sobering. The monoculture plantation model is never profitable under either the high or low case scenario.

Table 20: Net Margin Over 10 Years, One-Acre Monoculture *Jatropha* Plantation

Years	0	1	2	3	4	5	6	7	8	9	Totals
Net Low (Ksh)	-10,314	-8,542	-6,653	-7,038	-7,226	-6,505	-7,217	-6,946	-6,664	-6,664	-73,769
Net Hi (Ksh)	-10,314	-8,542	-6,653	-6,999	-6,314	-3,574	-3,422	-2,288	-900	-900	-49,905

The intercrop plantation model is never profitable due to large input costs and relatively low yields and spacing density (see Table 21 and Chart 17).

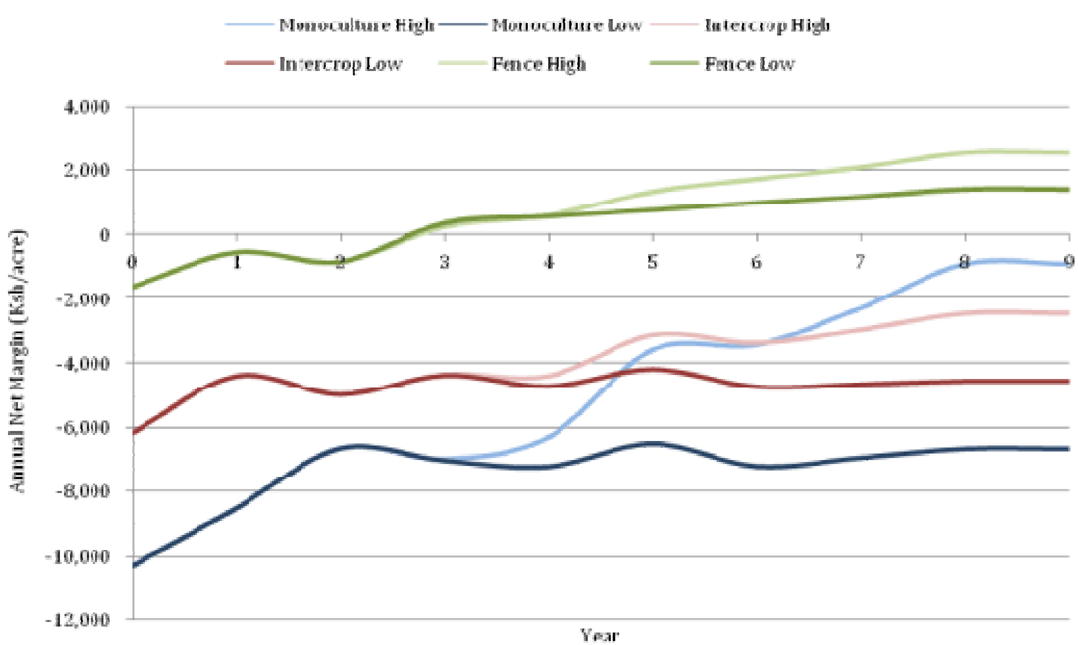
Table 21: Net Margin Over 10 Years, One-Acre Intercrop Jatropha Plantation

Years	0	1	2	3	4	5	6	7	8	9	Totals
Net Low (Ksh)	-6,177	-4,400	-4,985	-4,374	-4,722	-4,190	-4,743	-4,660	-4,558	-4,558	-47,366
Net Hi (Ksh)	-6,177	-4,400	-4,985	-4,359	-4,392	-3,127	-3,365	-2,968	-2,463	-2,463	-38,699

Only the fence plantation currently looks like a potentially appealing investment. Under both scenarios, the fence plantation turns an annual profit in the fourth year (see Table 22 and Chart 17).

Table 22: Net Margin Over 10 Years, One-Acre Fence *Jatropha* Plantation										
Years	0	1	2	3	4	5	6	7	8	9	Totals
Net Low (Ksh)	-1,618	-545	-836	373	574	783	1,011	1,212	1,441	1,441	3,836
Net Hi (Ksh)	-1,618	-545	-836	251	612	1,354	1,743	2,104	2,561	2,561	8,187

Chart 17: Net Margins for *Jatropha* Over First 10 Years, by Plantation Type and High and Low Scenario



The cumulative return is profitable after seven years under the high scenario and eight years for the low scenario (see Chart 18). The internal rates of return for the high and low fence plantation model are 24% and 15%, respectively, which represent attractive agricultural investments.

Chart 18: Cumulative Income for *Jatropha* Over First 10 Years, by Plantation Type and High and Low Scenario

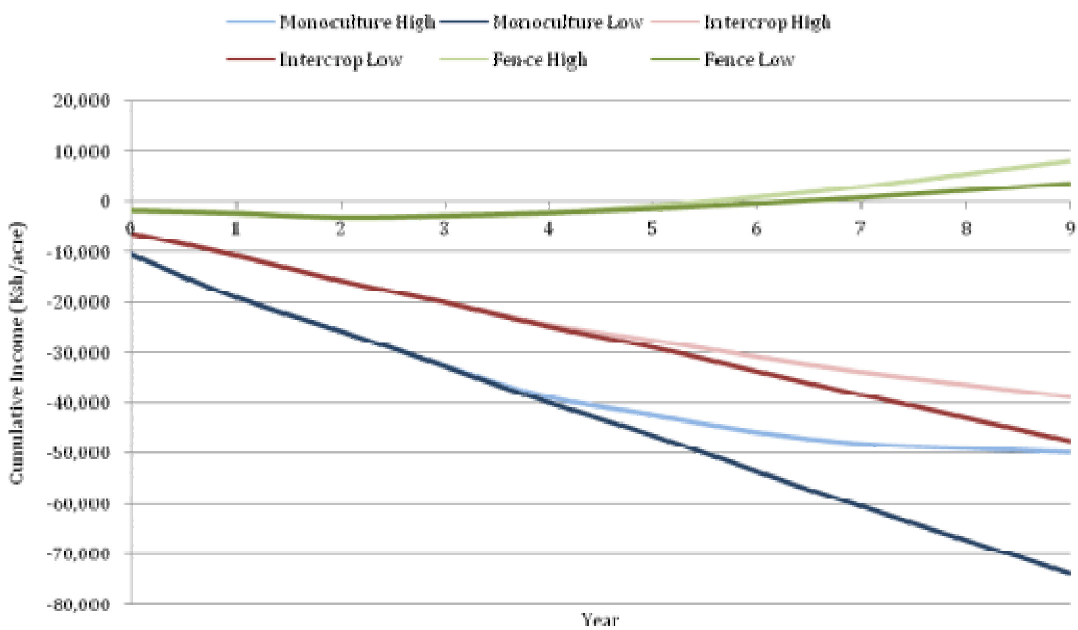


Table 23 shows the internal rate of return (IRR) for the three different *Jatropha* plantation investments at both high and low projected yields. Only the fence plantation shows a positive return over ten years, and a quite attractive one at that, especially under the high yield scenario.

Table 23: 10-Year Internal Rates of Return One-Acre Monoculture, Intercrop & Fence *Jatropha* Plantations

Internal Rate of Return (10 years)	Low – Yield Scenario	High – Yield Scenario
Monoculture	n/a	n/a
Intercrop	n/a	n/a
Fence	15%	24%

4.3.4 Opportunity Cost

Opportunity cost is the loss of potential gains from foregone alternative investments of time and resources. The question of opportunity cost is only relevant if each alternative investment promises some sort of net gain. It is futile to compare the utility of two investments where one will be profitable and the other not, since no rational actor would choose the unprofitable one. Therefore, considering the opportunity cost of growing *Jatropha* in lieu of other crops or land uses is only relevant if the *Jatropha* venture can be profitable. Reliable data on the net margins for alternative crops in Kenya is limited or unavailable, which makes it difficult to conduct a comprehensive opportunity cost analysis.

As indicated above, the only *Jatropha* plantation model that appears profitable for smallholders within a reasonable timeframe (less than ten years) is the fence. However, the opportunity cost of a fence is a somewhat strange concept, since there is generally very little, if any, alternative productive use of the border of a plot of land other than a fence. Moreover, if a fence can yield benefits beyond simply serving as a barrier or property demarcation line, those benefits are additional to and not in place of the value of the fence itself.

The question of opportunity cost is, more precisely, whether the economic costs and benefits of a fence made of *Jatropha* outweigh those of a fence made of some other crop, such as *Croton*. According to the economic analysis of *Croton* contained in Chapter 6 below, the projected internal rate of return for a *Croton* fence (including its value for sustainable timber) is about 4.2% after 20 years. A *Jatropha* fence appears to be a better investment with an IRR of between 15% and 24% after only 10 years, depending on the high or low yield scenario.

4.4 Production in Kenya

4.4.1 Historic Activities

Mature *Jatropha* tree in Raleida District, Nyanza Province.

While *Jatropha* is not indigenous to Kenya, it has been naturalized in many parts of the country. Farmers have also been growing it for many decades for reasons other than biofuels, such as many of the traditional uses listed above. Through the course of the field survey, many trees older than 30 years, and in some cases older than 50, were found being grown as fences or in the wild in places like Ralieda District in Nyanza Province, the Nguruman area of Kajiado District in Rift Valley Province, Muranga North and Muranga South Districts in Central Province, Kibwezi and Kitui Districts in Eastern Province, and Taita District and Shimba Hills in Coast Province. Older trees are also reported to thrive in and around Meru, although we were unable to conduct a comprehensive survey of that area.

Jatropha has been used for many years by medicine men in the Luo tribe of Nyanza Province, who call it "Jok." As a result, some Luo associate it with black magic or bad luck. In the Mtito Andei area of Kibwezi District bordering Tsavo National Park in Eastern Province, people have tried using *Jatropha* as a fence to prevent elephants from trampling and eating their crops, with mixed results.

In the year 2000 or so, a few individual farmers in western Kenya along the Ugandan border, such as Siaya, Vihiga, and Bungoma West Districts, began introducing *Jatropha* as feeders to support their vanilla vines. The *Jatropha* was planted not for its production of oilseed, but rather to serve as a host for the more lucrative vanilla crop, which can fetch up to Ksh 3,000 per kilogram. As a result no effort was made to nurture the *Jatropha* to produce seeds. This model has been adopted in Kilifi and Malindi Districts of Coast Province as well.

It is only within the past few years that *Jatropha* has become widely known as a potential biofuel feedstock among Kenyans. As word spread of this crop, large numbers of farmers, especially smallholders, began planting. Much of the initial enthusiasm came from a handful of NGOs (see Case Studies in the following section). Farmers were recruited with information mainly taken from the Internet, as few, if any, of these early promoters had conducted any multi-year research trials of their own to verify the claims they were making on productivity.

Vanilla vine supported by *Jatropha* tree in Kilifi District, Coast Province.

The initial impression was that *Jatropha* would produce prolifically with little or no inputs, even in marginal semi-arid areas. Desperate for new promising crops in which to invest, farmers agreed to purchase seeds for as much as Ksh 2,000 per kilogram that were often advertised as "certified" even though they were basically collected from older trees growing in the wild or around farms. The farmers were also promised extension services to support growing the crop, as well as a market for the seeds once the plants started producing. Unfortunately, many farmers surveyed reported having little, if any, support since planting and few, if any, buyers for the small quantities of seeds they have managed to produce.[lxxxix] With yields much lower than originally anticipated, many farmers have abandoned the crop.

4.4.2 Current Activities

The following section provides case studies of various *Jatropha* projects or clusters of growers throughout Kenya. Although most activities related to *Jatropha* consist of small-scale production involving NGOs and private companies working with outgrowers and/or small demonstration/trial efforts, stories of large-scale plantations continue to be reported.[xc] Most of these large projects involve foreign investors planning to plant thousands of acres on semi-arid land owned by the government or large private ranches. As of the date of this paper, no large plantations have commenced. Most of the ongoing activities consist of rather small-scale production involving NGOs and private companies working to promote planting by clusters of smallholder farmers.

An important research trial which will go a long way of closing the research gap emphasized by this study has recently been launched with support from DEG (Deutsche Investitions-und Entwicklungsgesellschaft MbH) and the German Ministry of Economic Cooperation and Development (BMZ). The project consists of an extensive three-year research program in a public-private partnership across East Africa. Nine private companies in Uganda (Multiple Hauliers), Tanzania (Minjingu Mines and TanWat) and Kenya (Vegpro, Socfinaf, Rea Vipingo, Kordes Roses, Lesiolo Grain Handlers, Tropical Farm Management) are planting ten hectares each of experimental field trials in different ecophysiological conditions. One smallholder led trial has been added in Western Kenya and one other may be set in Kibwezi. The results aim to shed light on the question: "Is Jatropha economically sustainable in East Africa?" and will be in the public domain by November 2011. Further details of the trials and the contacts of the managing company Pipal Ltd. can be found at www.degjsp.com.

Energy Africa Limited – Smallholder Outgrower Project

Kwale District, Coast Province.

Rain: 1,000-1,300 mm; Temp: 24-26.3°C; Elev: 50-730 meters.

The climate in the southern part of Shimba Hills in Coastal Province is monsoon driven. Most soils in the area are characterized by low structure stability and are sensitive to erosion and sealing. Local farmers in the area practice agroforestry, combining staple food crops like maize with commercial crops trees such as mangos, coconuts, and citrus. However, maize does not grow well in some locations due to poor soils. Livestock keeping also is not viable due to the presence of tsetse flies.

Eirik Jarl Trondsen, EA's Managing Director, Stephen Mwanza and assistant at Shimba Hills Field Office.

Energy Africa Limited ("EA") was established in January 2006 with the goal of increasing income for local farming communities by creating a commercially viable company producing an environmentally friendly alternative to fossil fuels. EA began experimental research trials with Jatropha in 2004 in Shimba Hills and began test growing with local farmers in June 2006. EA initially provided seeds and cuttings free of charge to about 800 smallholder farmers and even paid incentives to encourage planting.

In 2008, EA had signed contracts with 200 farmers with agreements on conditions and prices. As the contract farmers live scattered in the area south of Shimba Hills about 10 kilometers in diameter, EA has organized 10 group leaders who assist EA staff with daily extension services. EA provides the farmers with planting materials, technical advice, and subsidized pest and disease control. EA now sells seedlings at Ksh 1 each, recommends a spacing of 2 meters x 2 meters and pitting at 30 cm x 30 cm x 30 cm, and provides insecticides and sprayers free of charge. The company is currently buying seeds at Ksh 10 per kilogram.

Much of the information used to guide farmers was originally taken from the Internet and has proven incorrect or simply inapplicable to the situation and climatic conditions of Shimba Hills. Despite significant cost and time by the company and the farmers, a lack of agronomic understanding of the crop combined with unimproved seed germplasm has led to generally disappointing results. For example, farmers did not originally prune their trees or lay down mulch to prevent evaporation. Consequently most farmers have obtained very little harvest for the first few years. These events have


Isaac Chule Katiko standing next to defoliated Jatropha trees on his farm in Shimba Hills, Kwale District.

discouraged some farmers, while others continue to persevere with expectations of improved productivity once the trees have matured. Individual old *Jatropha* trees in Shimba Hills are doing well in terms on yields.

Despite low yields, EA has managed to start pressing oil from the seeds that are produced. It sells the oil for Ksh 100 per liter as a replacement for kerosene in lighting. EA also sells a specially designed lamp for burning the *Jatropha* oil efficiently. Each lamp is sold for Ksh 30.

However, a basic economic cost benefit analysis shows that *Jatropha* is likely not viable with current yields, even if they improve somewhat over the coming years. This is especially true in places like Shimba Hills where farmers do not have the capital to maximize their investment in new crops and can barely plant enough food crops on which to subsist. A typical household in the region may own a relatively sufficient size of land (10+ acres), but often have too few able bodied family members to engage in farming, so the land is not fully utilized. Hiring casual farm labor is also usually not an option at Ksh 150-250 per day. Agronomy and production economics can raise huge challenges for developing viable outgrower schemes (see the economic analysis below).

Tanzanian-made oil press used by EA to produce *Jatropha* oil.

We conducted a comprehensive survey of all farmers growing *Jatropha* in Shimba Hills as part of this survey and found that only 75 out of the original 200 were continuing to grow it. Of those, data on yield and management practices, among other things was collected from 70 farms. Taken together, farmers in Shimba Hills were growing a total of 50,500 trees on about 53 acres. The largest farms contained 6,000 trees on five acres, although the average farm contained 674 trees growing on about 0.7 acres.

The vast majority of farmers (76%, or 53 of 70) planted between February and December of 2006, meaning that their *Jatropha* trees were in their third year of growth at the time of the survey. This finding is itself telling, as very few new farmers have decided to begin growing *Jatropha* over the past two years. The main reason for this seems to be the extremely low yields reported by the year three class, which averaged 0.005 kilograms per tree, or 3.12 kilograms per acre (assuming 625 trees spaced 2.5 meters by 2.5 meters). This compares to a national average (excluding farms in Shimba Hills) of 0.203 kilograms per tree, or 126.88 kilograms per acre, in year three.

It is not entirely clear what has led to such low yields, as rainfall, temperature and altitude are similar to other locations with much higher yields. That leaves us to assume that a lack of proper management may be the largest contributing factor. However, we found that 77% of farmers used manure in Shimba Hills, compared with 44% of farmers elsewhere in the country. Similarly, a higher proportion of farmers in Shimba Hills used some sort of pest control (67%) compared with farmers in other locations (22%).

One reason for the lower yields may be the type and fertility of soils in the area. Most farms have very sandy soils with very low nutrients. According to John Lungwe Tuje, a retired agricultural officer with a 35 acre farm in Shimba Hills, a combination of poor initial management such as a lack of pruning, and poor soils have contributed to the low yields. Mr. Tuje has about 800 trees growing on approximately one acre. Despite the appearance of healthy growth, as can be seen in the photo to the right, he reports a total yield of only 0.5 kilograms all of last year.

John Lungwe Tuje inspecting one of his 800 *Jatropha* trees in Shimba Hills, Kwale District.

Another factor that may be responsible for the lower yields in Shimba Hills is the influence of the management by EA. Several issues may be at play here. First, the farmers were originally offered cash payments to plant, but soon those payments ceased. Second, farmers were provided instructions on how to manage the trees, such as pruning, that did not initially appear to aid production, so many farmers lost faith in the information they were receiving. Third, farmers had received inaccurate messages from EA's former Managing Director, who promoted *Jatropha* as a wonder crop that would grow without manure and had no pests. Although the current EA staff has corrected this misinformation, the general perceptions and expectations of *Jatropha* among farmers remain somewhat confused.

Another issue is the perception by many farmers that *Jatropha* requires significant time and resources to manage, especially to control weeds, which cannot be justified given the lack of yields in the first two years and limited resources available to tend to more important food crops. In fact, the local District Agricultural Officer and District Officer both commented that they generally discourage farmers to focus on *Jatropha* given the overall food insecurity in the area. The combination of all of these issues seems to have led most farmers to lose interest in maintaining the crop, which may explain why the performance is so dismal.

WWF-UNDP Small Grants Project – Jatropha Fencing with CBOs

Kilifi, Kwale, and Malindi Districts, Coast Province.

Rain: 550-1,300 mm; Temp: 24-26.7°C; Elev: 0-735 meters.

Coast Province is rich in biodiversity and wildlife, both of which are being threatened by unsustainable agricultural activities and increasing use of biomass fuels. Firewood and kerosene are the main fuels used for cooking and lighting. Environmentally sustainable and economically affordable alternative fuels are critical for sustainable rural development in the region.

Gogoni Trial in June 2008 (Fritjof Boerstler).

The United Nations Development Programme's ("UNDP") Global Environment Facility Small Grants Programme ("GEF-SGP") attempts to promote *Jatropha* plantations on wastelands and as buffer zones to protect the biodiversity of coastal forests. Out of concern over *Jatropha's* potential conflict with food, they have agreed to focus growers on planting *Jatropha* hedges around food crops. The project's specific objectives include: extracting oil from the seeds for lighting to replace the consumption of kerosene, reducing greenhouse gas emissions, establishing a sustainable marketing structure for *Jatropha* products; improving income and living standards; increasing vegetative cover to reduce soil erosion and land degradation, and reducing crop loss caused by wildlife with *Jatropha* fences.

UNDP's implementing partners, the German Development Service ("DED") and the World Wildlife Fund ("WWF"), have been working through five community-based organizations ("CBOs") in areas adjacent to threatened forests and located in diverse agro-ecological settings. Since August of 2007, the project partners have provided seed materials to interested farmers in the five CBOs. Three types of propagation are being tested: cuttings from Magadi, seeds from Tanzania, and seedlings from Malindi.

Close to 60,000 *Jatropha* trees have been planted since July 2007 through the project. CBOs have provided experimental plots for hedges and been testing which types provide better performance so that farmers may adopt the best propagation methods and seed provenances. Research trials have begun in three different agro-ecological zones (see Map 2 below for site locations):

Gogoni Trial (coastal lowland, sugar cane zone, sub-humid): The zone has the highest annual rainfall of all of the sites (over 1,400 mm) and was mainly used for sugar cane production until the Ramisi sugar factory collapsed in 1989. Although the zone seems to have one of the highest potential for rain-fed farming, it can only be classified as medium-potential due to low fertility, poor drainage, and salinity of the soil predominant in many areas. The former natural vegetation cover within the area was dominated by lowland rainforests, which only continue to exist in very small pockets.

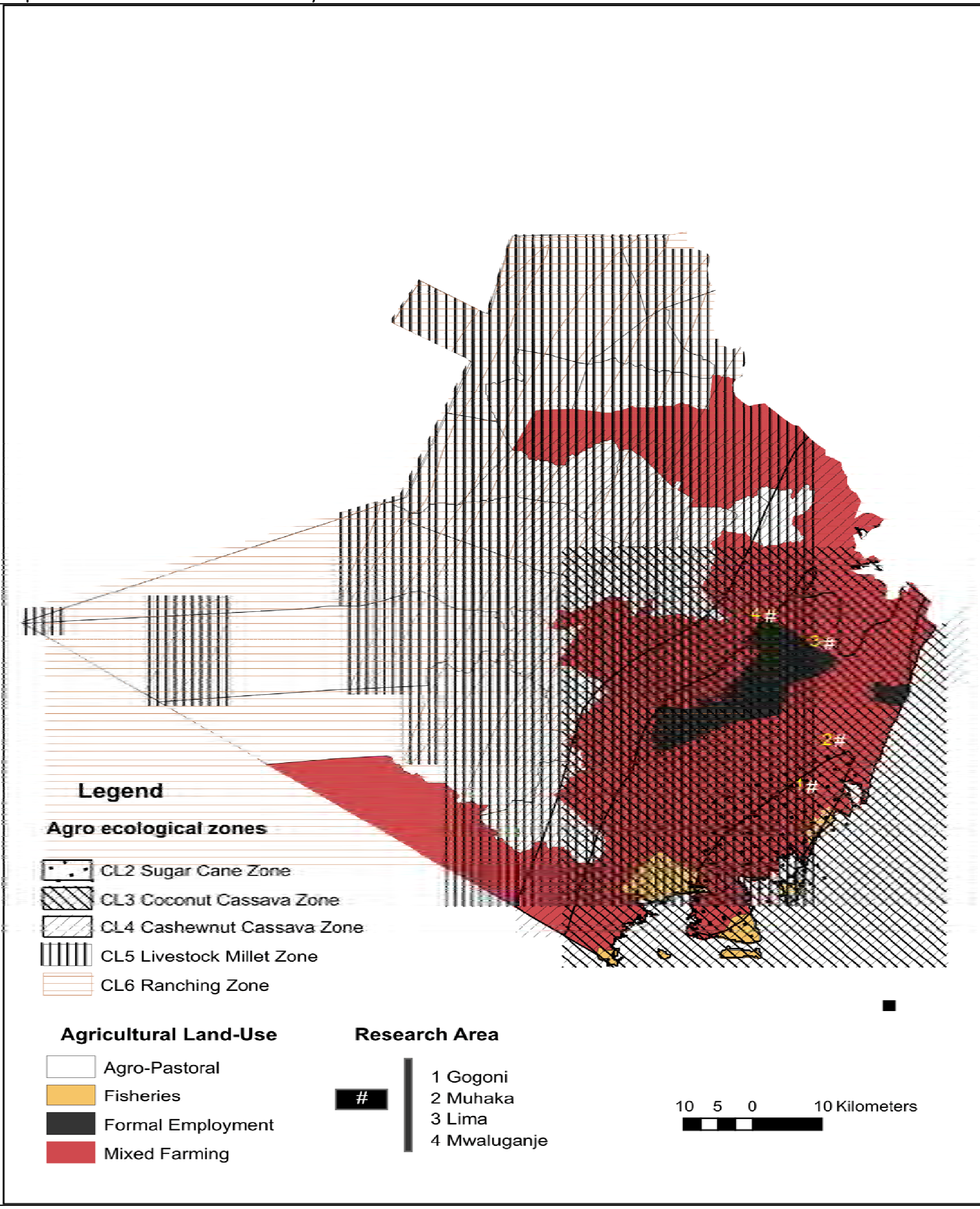
Muhaka + Lima Trial (coastal lowland, coconut/cassava zone, semi-humid): This zone has an annual precipitation of between 1,000 and 1,300 mm. Coconuts are the principal perennial crop grown within the area combined with maize and other annual food crops. Due to the annual precipitation and the low to very low fertility of the soil, the area is classified as having medium potential for rain-fed farming. However, some areas tend to have higher potential due to better soil fertility at the lower slopes of the Shimba Hills and small parts of the southern section. The natural vegetation is dominated by lowland moist savannah, lowland rainforest (in the southern part), and lowland dry forest and woodland (around Shimba Hills).

Mwaluganje Trial in June 2008 (Fritjof Boerstler).

Mwaluganje Trial (coastal lowland, cashewnut/cassava zone): Although the rainfall in this area is reasonably high, with a range from 800 up to 1,100 mm annually, the zone has one of the highest variability of annual rainfall in the region. Moreover, the soils within trial area are of poor to very poor quality. The natural vegetation consists of low woodlands and dry forest types, as well as an area of moist savannah in the south.

A monitoring and evaluation form has been developed to determine the productivity of the trees and to identify the most suitable growing zones for future expansion with regards to climate and soil conditions. *Jatropha* hedges in zones CL 2 and 3 (see Map 2 for zones) are able to produce 0.4 kilograms per meter of fence. At this yield, the project expects that a 250-meter long fence could supply enough oil for half of the average local household's annual lighting needs. As crude *Jatropha* oil cannot be used in conventional lamps, the project has developed a cost-competitive lamp, called AKIBA, that operates efficiently using straight *Jatropha* oil. For the expelling of oil the project has used a BP 50 manual press as well as a IBG Montfoort engine driven oil expeller from Oekotech (type CA 596) for demonstration purposes but is now designing a more efficient manual oil expeller which was being tested at the time of this report.

Map 2: Locations of WWF-UNDP *Jatropha* Trials[xci]



Vanilla Jatropha Development Foundation – Jatropha Promotion with Smallholders

Kibwezi District, Eastern Province.

Rain: 550-670 mm; Temp: 22.5-24.3°C; Elev: 656-1,008.

Kibwezi is located in a semi-arid part of Eastern Province, flanked by the Chyulu Hills and Tsavo National Park. People started settling in the area after independence and gradually started clearing indigenous forests and vegetative cover. Livestock grazing and agricultural practices have put pressure on local flora and fauna by squeezing out indigenous species, such as several types of *Acacia*. Major crops include maize, green gram, cowpeas and pigeon peas but they are subject to regular failure due to drought. *Jatropha* has been growing in the region for quite some time, mainly as natural fencing.

The Vanilla Jatropha Development Foundation ("VJDF") is a Kenyan NGO that was originally formed to promote Vanilla and *Jatropha* together. Its founders soon realized there was a lot of interest surrounding *Jatropha* and so began focusing solely on the latter crop. VJDF has operated in the Kibwezi area since 2006, as well as in some other locations in Kenya, such as around Mariakani in Coastal Province, and near Kisumu in Nyanza Province.

VJDF claims to have recruited more than 300 smallholder farmers to grow *Jatropha* in the Kibwezi and Mtito Andei areas, although only about a few dozen still seem to be growing it based on observations in the field. Several farmers surveyed in the area had purchased seeds from VJDF for Ksh 1,000 per kilogram or more. Another group of 11 farmers located in Nyanza Province purchased seeds from VJDF for an average of Ksh 1,114 per kilogram. The farmers were told that VJDF would provide ongoing extension services and would purchase the seeds they produced. Many farmers complained that they had not had much, if any support, since purchasing the seeds, and that no one from VJDF had returned to buy what little they had managed to produce.

Top: Francis Kaunda Kivuwgi and his family in front of their three acres of *Jatropha*. Bottom: Mr. Kivugwi and his wife dehulling and sorting seeds.

Despite the lack of support and the tough agronomic conditions that characterize the area, a few farmers surveyed were managing to persevere. However, even the most successful farmers are still far from breaking even on their investment. For example, Francis Kaunda Kivuwgi and his family (see photos on previous page) have 3,000 Jatropha trees on three acres, which he planted in April of 2006. Although the trees look better than most others in the area, Mr. Kivuwgi reports harvesting only 50 kilograms per acre (0.05 kilograms per tree compared with a national average of 0.141 per tree) last year. Asked what he did with the seeds, he said, "nothing, I have no buyers."

Overall, management practices, such as pruning and fertilization, are often neglected due to a lack of information or resources. Water is scarce throughout much of the year in this semi-arid region. With most available supplies going to drinking, cooking, and maintaining struggling food crops, little is left over for Jatropha and other cash crops. Pests and diseases are also common problems, and few farmers in the area have the resources or entomological knowledge to diagnose and control outbreaks before damage is done.

Yet, unlike other agroforestry species, such as Melia, an indigenous timber tree, and Acacia mellifera, an indigenous acacia, which can be adopted in the region and have vast market opportunities locally and nationally, there is no local market available for Jatropha seeds sold for oil. Many farmers interviewed had seeds available in quantities of dozens of kilograms, but no place to bring them for sale..

Even some of the most dedicated farmers are struggling. Samuel M. Kinyili planted seven acres in November of 2006 and has worked hard to maintain the plantation (see photo to the left). He weeds regularly and applies manure when available. Nonetheless, he harvested a mere 17 kilograms per acre (0.024 per tree in the second full year, compared with a 0.141 per tree average yield across the country). If he were to sell his seed at Ksh 15 per kilogram, which would translate into Ksh 60-70 per liter of oil after processing and transport, he would make a total of about Ksh 255 per acre. At the same time, he has spent thousands of shillings on land clearing, establishment, weeding, and manure.

Samuel M. Kinyili tending to his seven-acre *Jatropha* plantation in Kibwezi District.

This is especially true considering the opportunity cost of foregoing basic food crops on the same land. Three of the most common staple food crops grown in the area are maize, greengram, and cowpea. The crops are grown for subsistence and, if a surplus is produced, for cash to buy other basic necessities, like farm implements, salt, charcoal, kerosene, and building materials for shelter.

As Table 24 shows, an acre of maize and greengram, if sold, will net Ksh 658 and Ksh 1,041, respectively. The net margin for cowpea shows a slight loss. Thus, for Jatropha to be competitive with a staple food crop such as greengram in terms of annual revenue, a local farmer would have to yield over 20 times the amount of Jatropha seeds that he is currently able to obtain. Of course, annual input costs would presumably be less for a mature Jatropha plantation than for an annual crop, so overall revenue could be somewhat less to match the margins currently obtained with food crops. Nonetheless, a *Jatropha* yield increase of even 10 times what is currently being obtained — from 17 to 170 kilograms per acre — looks like it might take many years of slow maturation to achieve, if ever. In the meantime, farmers like Mr. Kinyili and Mr. Kivuwgi are foregoing much needed annual food crops.

Table 24: Net Margins for Competing Crops in Eastern Province

Crop	Cost (Ksh/acre)	Yield (kg/acre)	Price (Ksh/kg)	Revenue (Ksh/acre)	Net Margin (Ksh/acre)
Maize	3,383	449	9	4,041	658
Greengram	4,217	239	22	5,258	1,041
Cowpea	3,743	249	14	3,486	-257

Green Africa Foundation – Nursery, Demonstration Plantation and Outgrower Scheme

Kitui and Yatta Districts, Eastern Province.

Rain: 500-1,100 mm; Temp: 18-26°C; Elev: 1,100-1,300 meters.

Except Kitui town, most areas on the Yatta plateau are sparsely populated. The area is characteristically dry and, with no permanent river system, irrigation is difficult. Growing crops or trees is challenging, so many residents rely on charcoal production from indigenous forests as a main source of income. This has led to massive deforestation over the past several decades, yet potential alternatives remain underdeveloped. As a result, the Green Africa Foundation ("GAF") and other actors have targeted the area as a suitable place to promote *Jatropha*.

Green Africa's Emily Awori at the Kitui Nursery.

GAF was founded in 2000 to support ecological and environmental conservation, with a particular focus on arid- and semi-arid lands where poverty is most prevalent. The Foundation focuses on capacity development of poor communities through a partnership approach that integrates environmental conservation and community livelihoods.

GAF has developed a farm in Kitui into a nursery and demonstration facility (see photo to the left). The nursery supplies seeds and seedlings to *Jatropha* growers both large and small throughout Kenya for about Ksh 1,500 per kilogram or Ksh 30-50 per seedling. They claim to have seeds from various parts of the world, including China, Mali, Tanzania, and, here in Kenya from Nguruman and Meru areas, and have observed and recorded some characteristics of seedling growth from the different varieties.

With the assistance of the Prince of Monaco, GAF established a demonstration farm in Kyusyani village in December 2007 (see photo to the right). Three-month old seedlings were planted in December 2007 and March 2008 on about five acres of land. No irrigation is being used, although GAF is experimenting with weeding, pruning, and pest control. The plan is to add more trial plots to test various types of intercropping.

Six-month-old *Jatropha* growing at GAF's Kyusyani Village demonstration plantation.

GAF has used the nursery and demonstration trial plot to promote *Jatropha* planting among local farmers. Most of the farmers are small scale, having purchased between one and two kilograms of seeds each from

GAF. They are generally self-organized in farmer groups and predominantly practice intercropping. No oil is yet being produced, as seeds are being used to expand plantations and for sale to others.

Better Globe Forestry – Test Plantation

Kiambere, Eastern Province.

Rainfall: 600-700 mm; Temp: 27-28°C; Elev: 715 meters.

Better Globe Forestry (BGF) is a registered Kenyan company that aims to foster development through reforestation projects with drought-tolerant species such as *Jatropha*. In late 2006 and early 2007, BGF planted 68,400 *Jatropha* trees on about 130 acres of land adjacent to the Kiambere Reservoir. The remainder of the 250-acre test plantation is planted with *Mukau* (*Melia volkensii*) and *Neem* and is located on 5,000 hectares that has been allocated to BGF by the Tana and Athi River Development Authority.

View of BGF's 250-acre test plantation from the adjacent Kiambere Reservoir in Eastern Province.

The reservoir is the result of a hydroelectric dam on the Tana River. Due to the arid climate, poor soils, and a lack of resources for inputs by local farmers, growing rain fed crops is extremely challenging. Food insecurity in the area is a serious problem, as subsistence crops fail on average two out of every three years due to lack of rain. The land that was allocated to BGF has experienced severe erosion over the years from local villagers squatting on the land.

The most productive plot of *Jatropha* (selected as such by the farm manager for use in this survey) includes 8,000 trees spaced 2.5 by 3.5 meters apart on just over 17 acres. After two years, the plot has produced about 216 kilograms of seed, or 0.027 kilograms per tree. This compares with an average of 0.141 kilograms per tree for two-year-old monoculture plantations throughout Kenya. Poor agro-climatic conditions and severely degraded soils certainly contribute to the low yields. Various efforts are being made to reduce erosion and begin restoring soils, although no fertilizer is being applied.

What is most remarkable about this plantation, other than its relative size, is that it is one of the few in Kenya to be located in the harsh conditions that many *Jatropha*

View over Kiambere Reservoir from BGF's *Jatropha* trial.

proponents claim it can thrive in. Given these yields, BGF believes that *Jatropha* will be very challenging, if not impossible for smallholders to grow successfully and profitably. Ready access to a market to sell seeds is another challenge for smallholders. This is why BGF believes in establishing a nuclear plantation to support outgrowers that take up the crop.

Despite low yields, BGF has expertly managed the test plantation and invested significant resources.

The following list provides a description of inputs and costs:

- Seeds: 16 kilograms @ Ksh 800/kg for 8,000 trees.
- Land Preparation: 840 person/days for pitting, 40 person/days for marking. 4 jembes and sisal twine for Ksh 3,000.
- Planting: 100 person/days. 20 crates for Ksh 8,000.
- Replanting: 13% mortality requiring 5 person/days.
- Irrigation: 4 liters per tree per week times 8,000 trees for a total of over 1.5 million liters. Water is taken from the reservoir at no cost. Labor is extensive, requiring 2,600 person/days per year for the 8,000 tree plot.
- Fertilizer: none used.
- Pest and Disease Control: Applied on average three out of four weeks. Various chemicals are used, according to prescription. 216 person/days are required to apply the controls.
- Weeding: Conducted three times per year, requiring jembes costing Ksh 7,500 and 343 person/days per year.
- Harvest: One harvest in second year, yielding 216 kilograms, which were sold to a local oil processor for Ksh 12 per kilogram.

As shown in Table 25, BGF has spent close to Ksh 700,000 over two years to establish and manage roughly 8,000 trees on 17 acres. That amounts to about Ksh 42,000 per acre. In return, it has earned a mere Ksh 152 per acre. At this rate, it is hard to imagine the venture becoming profitable.

Table 25: Costs and Revenue for BGF's 17-Acre Test Plantation		
Cost of Production	Year 1	2
Inputs (Ksh)		
Seeds	12,800	0
Planting, Weeding & Pruning Equip.	18,500	1,850
Irrigation Equip.	4,200	420
Water	0	0
Manure	0	0
Pest/Disease Control	various	various
Inputs Sub-Total	35,500	2,270
Labor (Ksh)		
Land Preparation	123,200	0
Planting	13,020	0
Fertilization	0	0
Irrigation	364,000	364,000
Pest Disease Mgmt.	30,240	30,240
Weeding	48,020	48,020
Labor Sub-Total	578,480	442,260
Cost Total (Ksh)	613,980	84,996
Revenue		
Yield (kg/tree times 8,000 trees)	0.00	216
Farm-Gate Price (Ksh/kg)	12	12
Revenue Total (Ksh)	0	2,592
Net Margin (Ksh)	–613,980	–82,404
Cumulative Return (Ksh)	–613,980	–696,384

Fortunately, BGF's interest goes beyond short-term profits at this point. One of the major objectives of the Kiambere plantation is to experiment with various technical and management practices for a large-scale, mechanized, monoculture *Jatropha* plantation, especially regarding spacing, weeding, and pruning. BGF believes that intercropping *Jatropha* with food might work in more agro-ecologically favored regions receiving 800 mm or more of rainfall per year. In relatively drier areas like Kiambere, crops face extreme competition with water and nutrients, and a mixture of two different species could result in lower yields for both species.

A lack of scientific knowledge on agronomic aspects of *Jatropha* creates uncertainties regarding yields and costs of production. Like many others, BGF initially relied on information available on the Internet regarding *Jatropha*, but soon realized that the information was in stark contrast with what was happening on their fields. Overall, *Jatropha* is much less drought-resistant and more prone to pests and diseases than advertised, especially during its establishment phase. Young *Jatropha* is very vulnerable, requiring intensive treatment during the initial couple of years, which subsequently increases production costs.



Left: Management practices, such as surrounding young seedlings with mulch, help maximize survival. Middle: *Jatropha* test plantation. Right: Fruiting from two-year-old trees.

As an expert forestry company, BGF's experience with *Jatropha* underscores the critical need for stakeholders to engage in both short- and long-term research. The short-term strategies include the development of optimal silvicultural practices (spacing, pruning, fertilizing, spraying, etc) depending on agro-ecological and soil conditions. The long-term strategies involve the selection of good provenances for the development of genetically improved seeds, which are high yielding, drought-resistant, and contain high-oil contents. To this end, BGF has been an early proponent of and participant in a recently launched *Jatropha* research trial, along with ICRAF, Endelevu Energy, KEFRI, KARI, Energy Africa, and others.

Namrolwe Jatropha Farmers Group

Bondo-Ndori-Asembo Bay, Nyanza Province.

Rain: 1,130-1,500 mm; Temp: 22°C; Elev: 1,150-1,300 meters.

The north shore region of Lake Victoria from Asembo Bay, Ndori to Bondo, often suffers from food deficits as farmers are poor and generally cannot afford fertilizer. Thus, optimal production is rarely attained. In the past, farmers in the region were introduced to new cash crops and encouraged to plant them but they were often disappointed by low prices and a lack of markets compared to what had been promised. The Bondo District Agricultural Officer thinks that the Ministry of Agriculture should hesitate to promote new cash crops, including *Jatropha*, until farmers are assured good access to markets and reasonable prices.

A farmer dehulling *Jatropha* seeds from an old tree estimated to have been planted by a late medicine man over 50 years ago at her farm in Rarieda District, Nyanza Province.

Jatropha, called *Jok* locally, has been grown for years by medicine men in the region. A Norwegian NGO called Aro, is said to have first introduced the idea of *Jatropha* as a biofuel crop. The Namrolwe *Jatropha* farmers group was formed initially by a small number of farmers in Ndori in late 2006. By February 2009 it had about 100 members, most of them planting between 100-300 trees on 0.25-0.5 acres each. The seed material for planting was either collected from the local old trees or sourced from Nguruman by the KEFRI Maseno office. German, Swiss, and Italian investors once came to visit the farmers group in late 2008.

In February 2009, the chairman and secretary of the Group led us on a tour of four farms. One farmer, named Abigeal Ogara, was introduced as the best performing farmer in the group. She had planted 105 *Jatropha* trees spaced 1.5 by 1 meters apart. At the time of the visit, the trees were 1.75 years old and the farmer had harvested 25 kilograms from the plot, or about 0.24 kilograms per tree. The farmer sold 20 kilograms of seed to Swedish visitors at Ksh 1,000 per kilogram.

The Secretary of the Farmers' Group, Mr. Okia, next to one of the 270 trees growing on Clament Odongo Dula's 15-acre farm in Bondo District, Nyanza Province.

Another farmer, Clament Odongo Dula, had planted about 270 trees planted two years before on about 0.25 of his 15-acre farm. Mr. Dula reported a harvest of 50 kilograms, for an average of

0.185kilograms per tree. However, only about 90, or 30%, of his trees had produced anything. Although all the trees were planted at the same time and treated the same, the farmer could not explain what factors cause mortality and low growth in some trees but not others. Another farmer visited complained that pests and diseases had attacked her plot and resulted in low yields of about 0.02 kilograms per tree. On the last farm that we visited, the Jatropha trees were very small, with few branches, and no yields after two years.

There is still too much uncertainty over agronomy for farmers to be encouraged to expand production in the area. In addition, occasional foreign visitors who buy a couple dozen kilograms of seeds for testing at Ksh 1,000 or more have seemed to create expectations of a continuous and steady market at those prices. Many farmers interviewed had not even considered that prices would need to be about 1% of that, or Ksh 10 per kilogram, in order to create a steady local market for biofuel production.

4.4.3 Acres Under Production

As part of the survey, we visited a total of 289 farmers growing approximately 208,000 Jatropha trees on a total of just over 218 acres. The mean and median plot sizes were 0.88 and 0.25 acres, respectively. The mean and median number of trees per farm was 737 and 200, respectively. Based on interviews with local officials in each area where the survey was conducted, we estimate that the survey may have included about 60% of all Jatropha farmers growing in those areas. Including these farmers would add about 189 farmers to the ones we surveyed, for a total of 472 Jatropha farmers across Kenya. Assuming the same average plot size and number of trees per farm, these additional farmers would increase the total acreage to about 384 acres, containing roughly 347,000 trees.

We are also aware of at least one location that we were unable to include in the survey due to time and resource limitations. It is a project, called the Jatropha Integrated Energy Project, that the organizers, Norwegian Church Aid, claim has recruited nearly 1,500 cotton growers in Mpeketoni, which is near Lamu in Coastal Province. Farmers began planting between May and July of 2008, and the project coordinator claims that over a thousand farmers planted about 300,000 Jatropha trees in 2008, although this has not been verified independently. Each farmer is said to have committed between 0.25 and 2 acres. This project could dramatically increase the amount of Jatropha being grown in Kenya, but it is too early to determine to what extent.

Finally, the totals above do not include the research plots being managed by professional agronomists described in some of the case studies above, including the GAF, BGF, and WWF-UNDP trial sites. According to surveys of these sites and interviews with the organizations operating them, we calculate an additional total of about 75,000 trees on 135 acres. Thus, the current estimated total production of Jatropha in Kenya, excluding what has been planted in Mpekitoni, is about 422,000 trees on about 519 acres.

4.4.4 Mapping and Overall Suitability

In addition to identifying the most attractive plantation type, we have also attempted to locate the optimal geographic locations to focus investment. To accomplish this we incorporated three categories of data into the following maps: agronomic suitability, market accessibility, and potential conflicts with existing land uses, including food, cash crops, and gazetted areas.

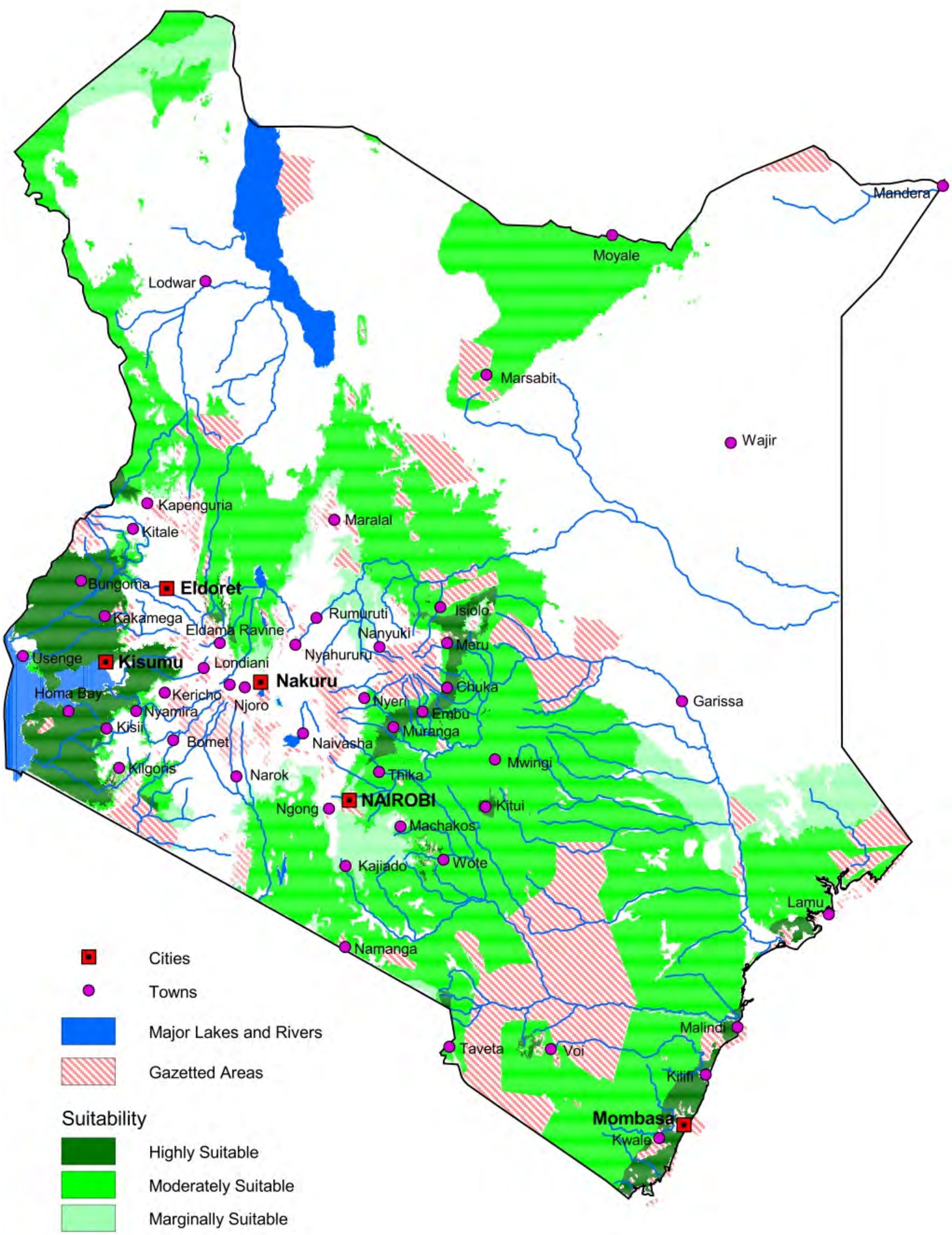
The *Jatropha* suitability map (Map 3) utilizes the agronomic conditions contained in Table 26 and described in more detail in Section 4.2.1. Suitability is divided into areas that are considered highly, moderately, and marginally suitable according to the range and optimal growing conditions listed above. 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.

Table 26: Range and Optimal Agronomic Suitability for *Jatropha*		
Agronomic Parameters	Range	Optimal
Annual Temperature (°C)	12.7-33.3°C	19.3-27.2°C
Annual Rainfall (mm)	440-3,121 mm	1,000-2,000 mm
Altitude (m)	0-1,800 m	n/a
Soil	Well drained, sandy soils w/ pH < 9.	

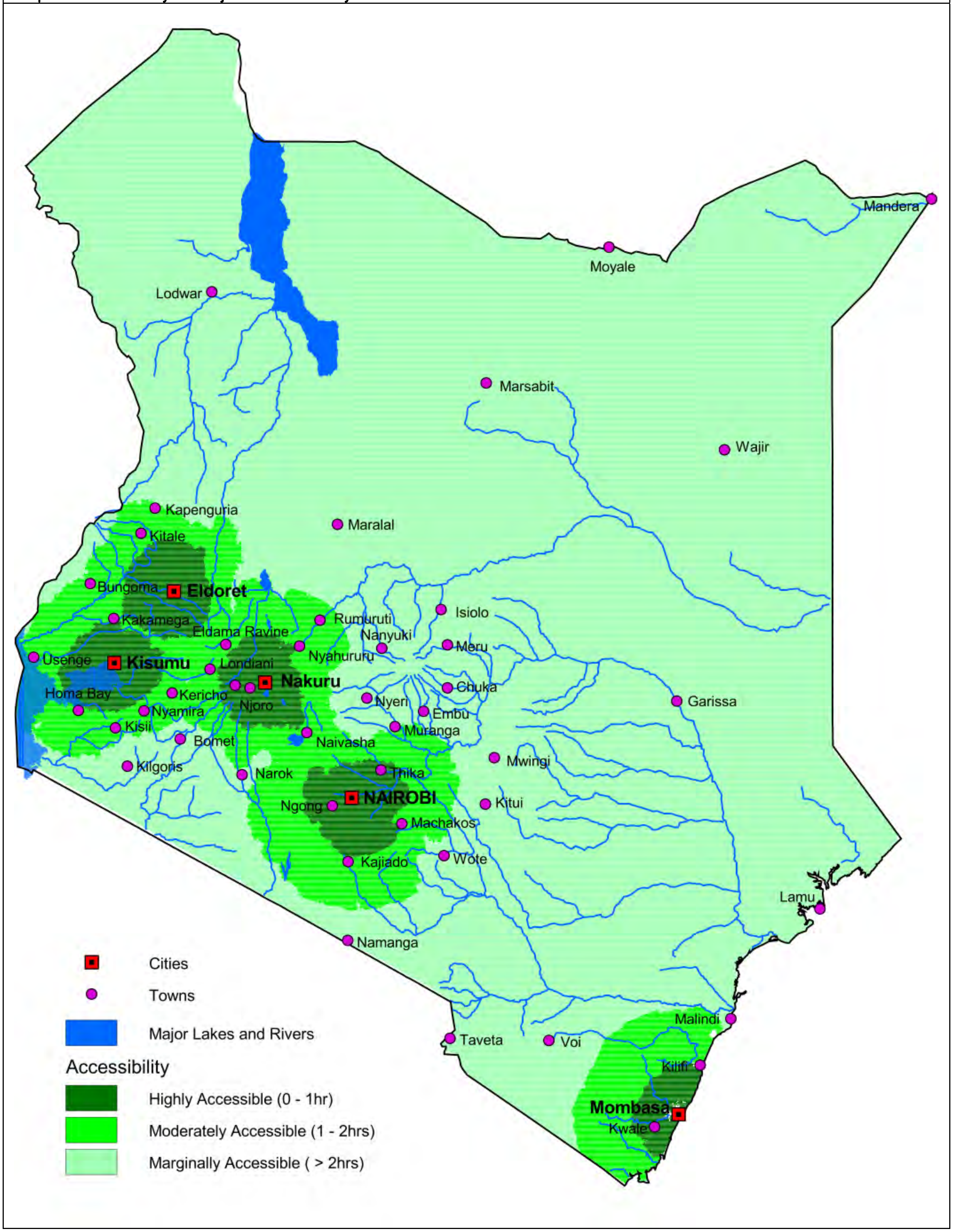
For market accessibility, we created two maps. Map 4 shows accessibility to major cities, including Eldoret, Kisumu, Mombasa, Nairobi, and Nakuru. Map 5 shows accessibility to major towns throughout the country. The idea was to depict accessibility for large-scale commercial investments in the first map and smaller-scale projects in the second. For both maps, accessibility is a factor of the time it generally takes to travel to the nearest city or town, according to existing road network, slope, land-use, land-cover, urban centers, and rivers and lakes.

We then combined the maps to show both suitability and accessibility together (see Maps 6 & 7). These maps use a colored grid to depict and overlay three grades of suitability — highly, moderately, and marginally — with the three grades of accessibility. A final set of maps overlay existing food and cash crop growing areas with those locations that are potentially suitable for the select oilseed crop, in this case *Jatropha* (see Maps 8 & 9).

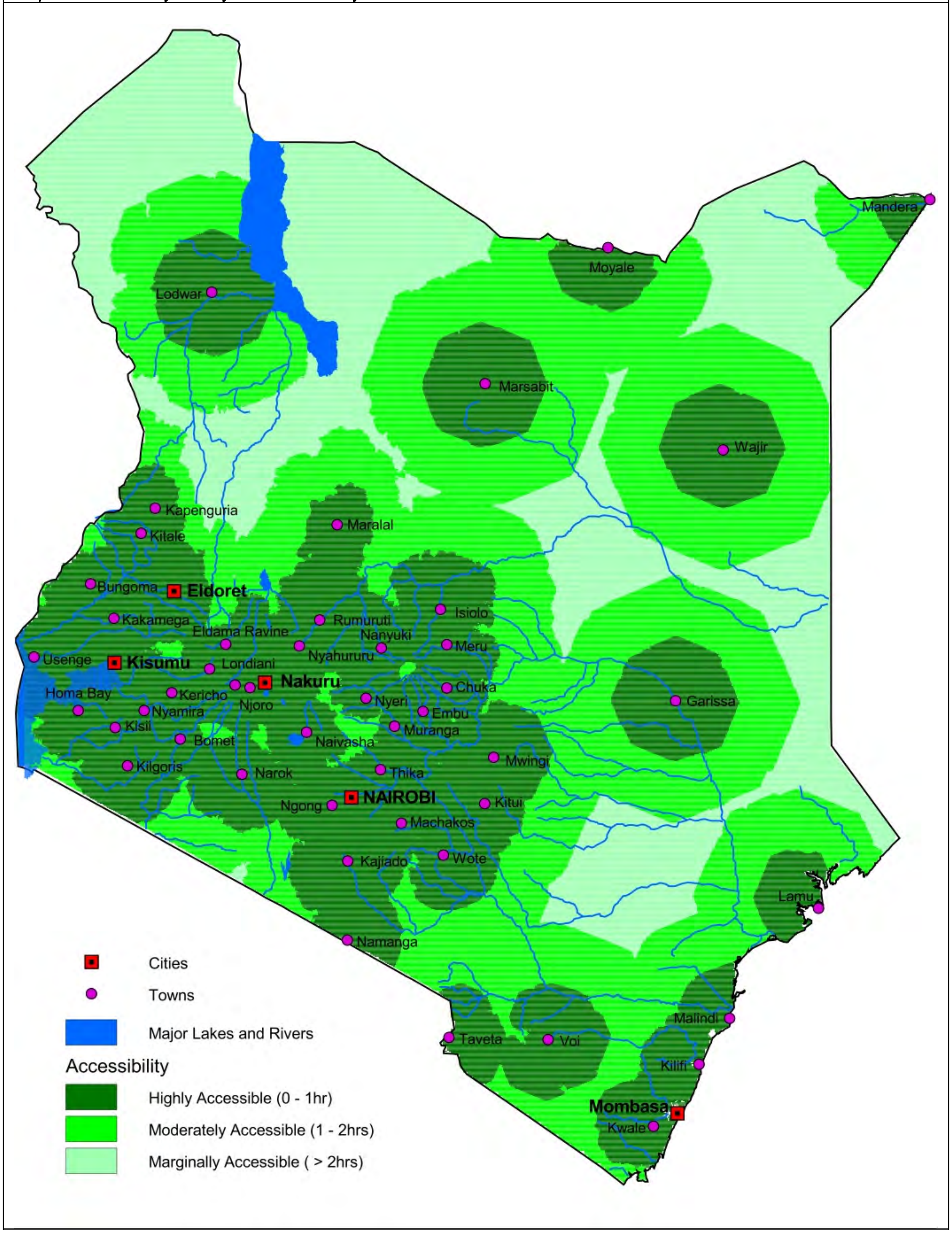
Map 3: Agronomic Suitability of *Jatropha* in Kenya



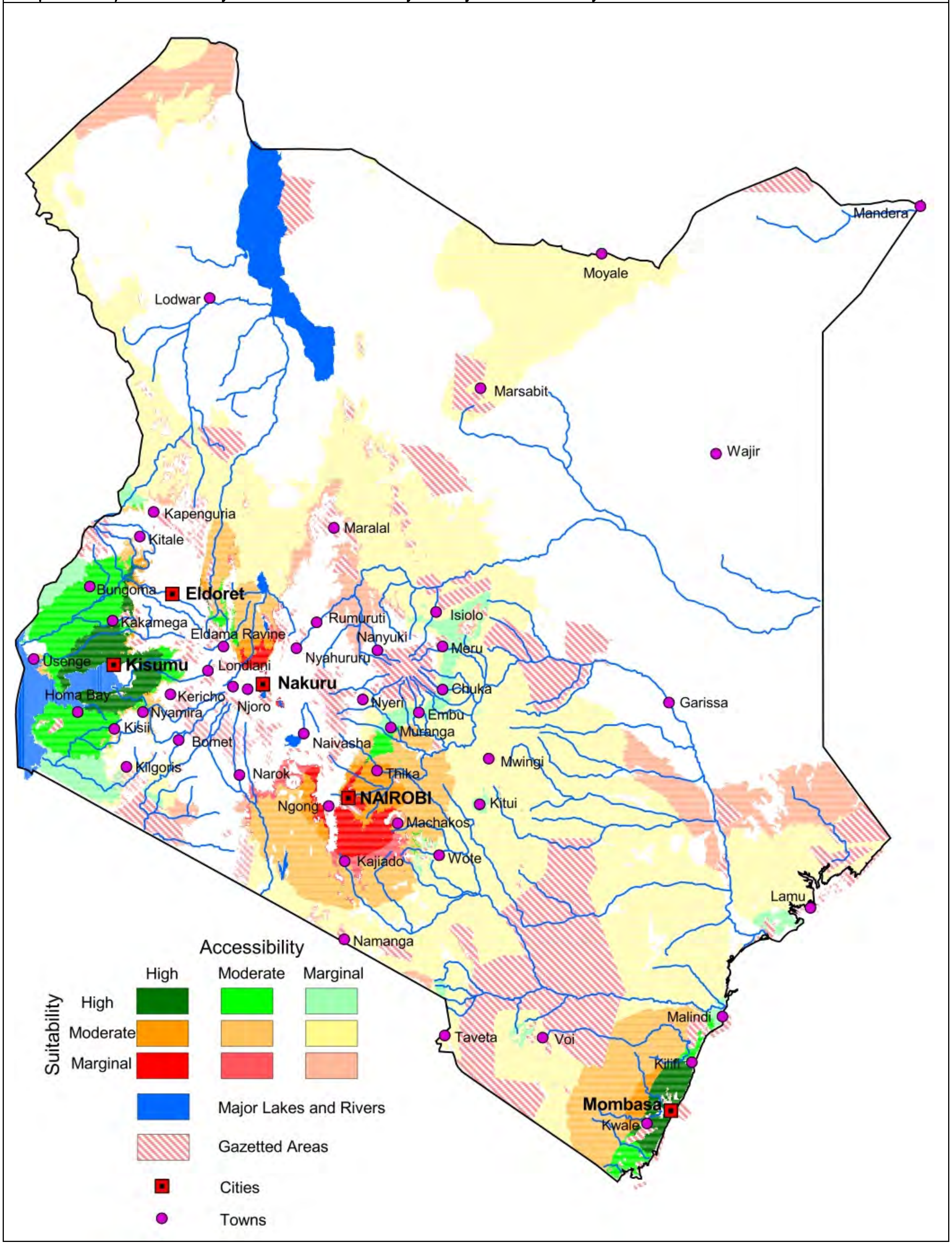
Map 4: Accessibility to Major Cities in Kenya



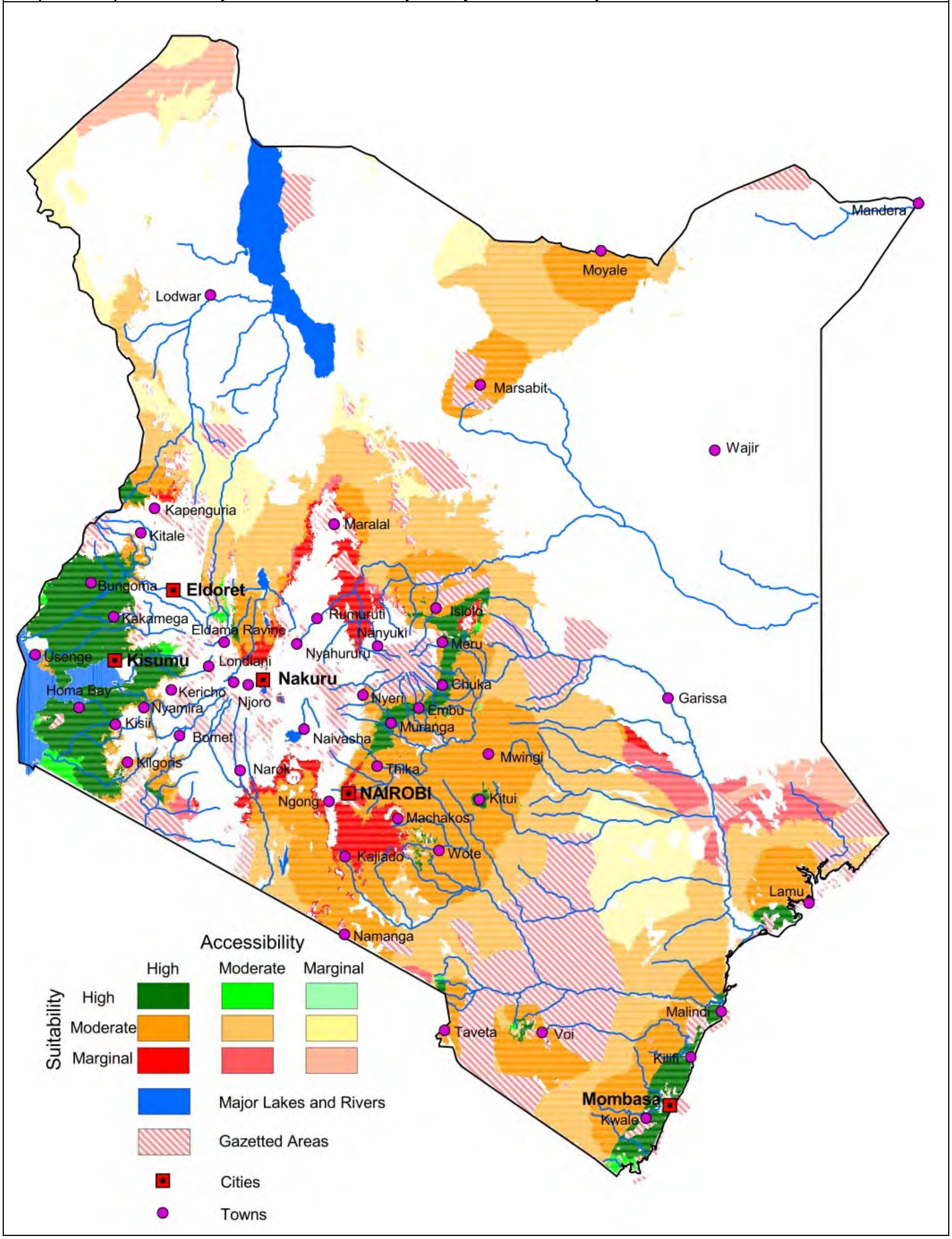
Map 5: Accessibility to Major Towns in Kenya



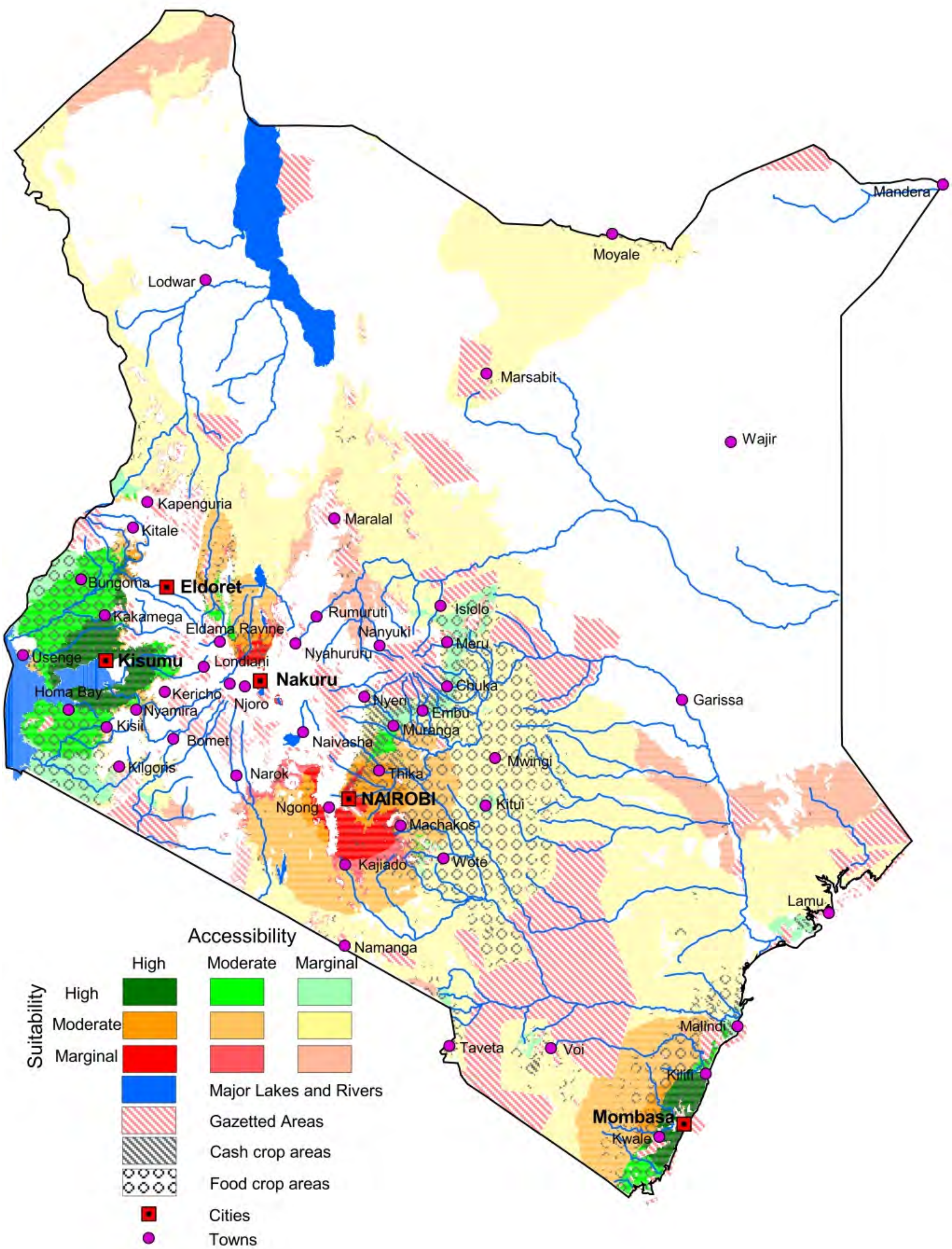
Map 6: *Jatropha* Suitability & Market Accessibility to Major Cities in Kenya



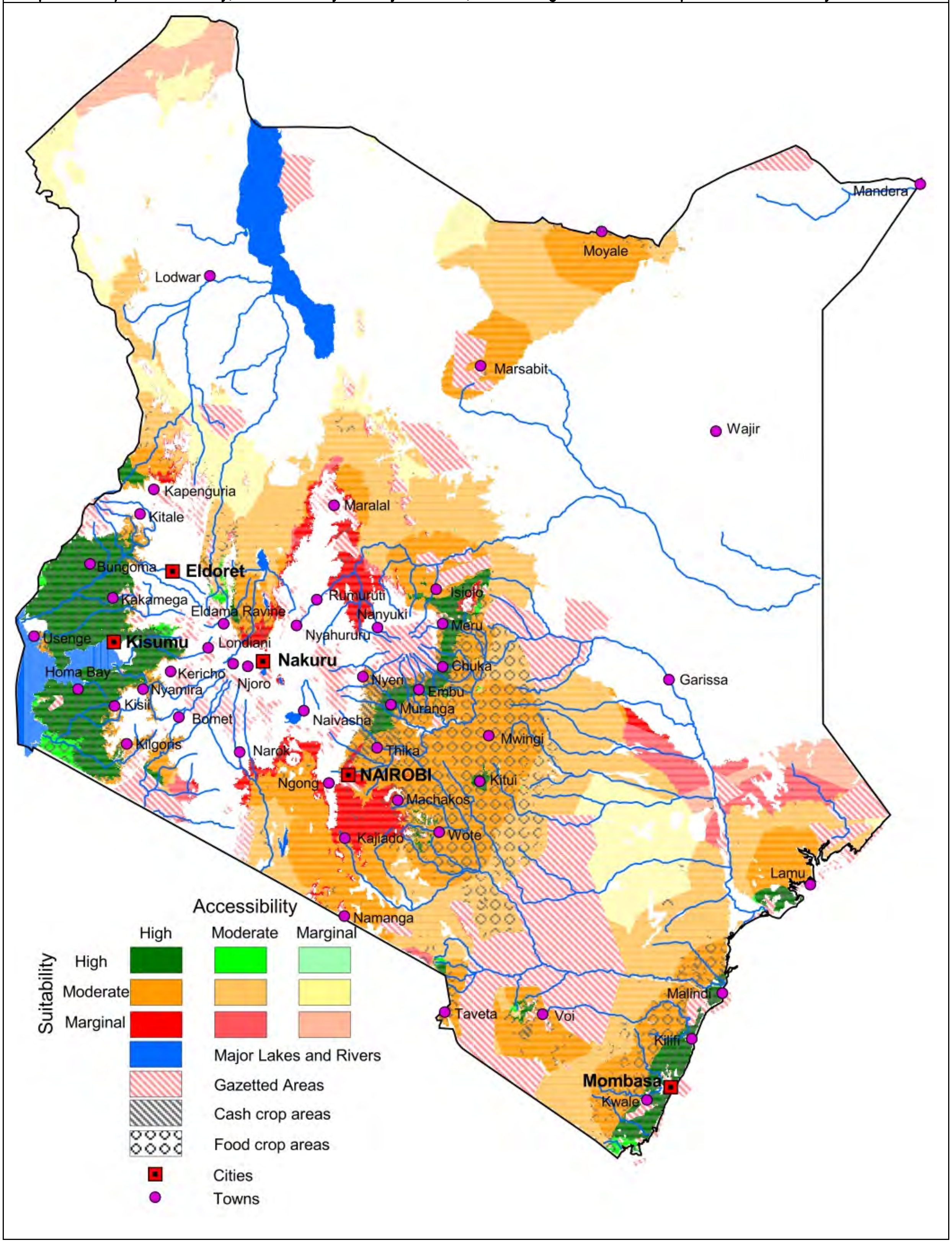
Map 7: *Jatropha* Suitability & Market Accessibility to Major Towns in Kenya



Map 8: *Jatropha* Suitability, Accessibility to Major Cities, & Existing Food/Cash Crop Land-Use in Kenya



Map 9: *Jatropha* Suitability, Accessibility to Major Towns, & Existing Food/Cash Crop Land-Use in Kenya



4.5 Outlook, Potential and Obstacles

Jatropha could be a complementary component of a diverse livelihood strategy that contributes to overall increased agricultural productivity. These strategies include investing income earned from biofuels crops into agricultural inputs to improve yields of food crops, providing alternatives to charcoal and firewood for lighting and cooking, and better utilization of resources in disadvantaged locations. However, the lack of scientific knowledge on agronomy, such as high-yielding seeds, best management practices, and optimum soil fertility, inhibits the delivery of effective farmer extension services. Another obstacle is that most growers are geographically dispersed and have yet to produce large enough quantities of seeds to achieve the economies of scale necessary for efficient biofuels processing. A final problem involves whether smallholder farmers with little access to capital can afford to wait the years it will take to recoup their investment and start making a profit.

Based on the in-depth field research that serves as the foundation of this study, and the economic analysis we have conducted using actual costs and yields, we conclude that smallholders in Kenya should not pursue *Jatropha* as a monoculture or intercrop plantation crop at the present time. It simply makes no economic sense for farmers, especially those that are food insecure, to be investing in a crop that will fail to yield positive returns. Further investments in monoculture and intercrop plantations by smallholders should be delayed until more research leads to yields high enough to justify the investment.

The only type of *Jatropha* plantation that we can recommend for smallholders at this time is the fence. Not only does this survey show that a *Jatropha* fence can be a sound investment for the farmer, but it is also a widespread, existing use of *Jatropha* that farmers are aware of and would likely be willing to adopt quite easily without reducing food production. The fence also has the additional benefit of protecting valuable plantation crops from trespassing wildlife and people.

The potential for oilseed production from the widespread adoption of *Jatropha* fences is limited from the perspective of large, commercial biodiesel production, but could play a significant role in the local production and use of various bioenergy products. For example, if 25,000 farmers each fenced one acre of land, enough seeds could be produced after seven or eight years to produce between 681,250 and 1,143,750 liters of oil and between 2,043,750 and 3,431,250 kilograms of eco-charcoal, fertilizer, or biogas feedstock annually. Such production would also mean between about Ksh 30 million and Ksh 64 million per year more in additional income to those farmers.

5. Castor

Ricinus communis (*Castor*) is a perennial shrub from the Euphorbiaceae family that likely originated in Abysinnia, or modern day Ethiopia.[xcii] Seeds have been found in the tombs of Egyptian kings dating back over four millennia, as the oil derived from the seed was commonly used in wick lamps.[xciii] *Castor* oil's extremely high hydroxic oil content, low freezing point, and high viscosity make it very suitable for various industrial applications. The oil is an ancient product that has been in use for thousands of years as lamp oil, unguents, medicines, and more recently, for a long list of industrial applications. An established global market exists for different grades of *Castor* oil, from crude, to industrial, to pharmaceutical.

Left: Two year-old Castor growing on Josephat Mbete Kanyale's farm in Yatta District, Eastern Province. Middle: Four month old Castor growing on Ronald Mavumbo's six acre Taita farm in Coast Province. Right: Wild Castor growing on horticulture farm in Kajiado District, Eastern Province.

5.1 Overview

5.1.1 Names

Scientific Name: *Ricinus communis* L.

Common Names: *Castor*, *Castor* seed, *Castor* bean, Palma Christi, Mbalika (Swahili).

The name "Ricinus" means tick in Latin because the ancient Romans believed the seeds looked like blood-engorged dog ticks.[xciv] The ancient Greeks called it Kiki.[xcv]

5.1.2 Description

Castor is a shrubby plant with green or reddish to purple stems and fingerlike leaves. In the wild, Castor can reach up to 9 meters, but cultivated varieties generally grow to between 1-4 meters.xcvi The leaves are palmate, with 5-11 incised lobes.xcvii Reddish brown or greenish white unisex flowers grow in narrow vertical inflorescence with female flower towards the top. The fruit has three lobes, within each form a shiny seed. The seeds are white, black, or red, with black spots, and are flattened in shape with brittle testa enclosing a white, oleaginous kernel.xcviii Dwarf-hybrid varieties grow to an average height of between 0.9 to 1.5 m, compared with between 1.8 to 3.7 m for normal varieties.[xcix]

Of the 17 farms that we visited that were growing *Castor* where measurements were taken, Table 27 contains the mean and median age, height (meters at breast height), number of branches, and number of fruits per branch. The *Castor* plants at six of the 17 farms were not flowering.

Table 27: Physical Characteristics of *Castor* Observed in Survey

Age (years)		Height (mbh)		# of Branches		# of Fruits	
mean	median	mean	median	Mean	median	mean	median
7.33	1.04	2.98	2.78	8.71	7.17	11.75	8.00

5.1.3 Uses

Castor oil is a pale yellow, viscous, and generally odorless liquid. It is composed of about 85% ricinoleic acid (12-hydroxy oleic acid), making it soluble in alcohol, meaning that it can be converted into biodiesel without external heat, unlike other vegetable oils.[ciii] No other vegetable oil contains such a high proportion of fatty hydroxy acids. Combined with its high molecular weight, low melting point, low solidification point, and extremely

Kihara Guchie's farm in Nyadarua District, Central Province.

high viscosity, make it one of the most valuable industrial oils.[ci]

Castor oil has over 700 uses, from medicines and cosmetics, to plastics and other industrial applications, to biofuel.[cii] It is used for engine lubrication, hydraulic fluids, explosives, dyes, nylon, plasticizers, soap manufacture, food processing, coatings and inks, insecticides, surfactants, polyurethanes, paints and varnishes.[ciii] The list of industrial chemicals and substances derived from *Castor* oil include: nylon-11, hydrogenated oil, dehydrated oil and its fatty acids, sulfated and sulfonated oil, sebacic acid, ethoxylated oil, polyurethanes, and oxidized and polymerized oil.[civ] In many parts of the world, *Castor* oil has many traditional uses as laxatives, purgatives, and for domestic lighting.[cv] The seedcake can be used for fertilizer and the leaves as a feed for eri silkworms.[cvi]

5.1.4 Environmental Impacts

Castor is indigenous to Kenya, but considered invasive in other parts of the world.[cvii] It can be grown as an annual or perennial and is suitable for manual harvesting as well as mechanization on a large scale. It is generally easy to cultivate, although yields will be enhanced through more intensive management. *Castor* does best on fertile, well-drained soil, and therefore it may compete with food production on arable land.[cviii] However, as the suitability maps below indicate, *Castor's* ability to grow on semi-arid lands may enable land-use planners to emphasize production on more marginal, underutilized land. Importantly, *Castor* is known to exhaust the soil very quickly, requiring the addition of fertilizers for continual production.[cix] Intercropping with crops that help to replenish soil nutrients may also help maintain soil nutrient levels.

Ronald Mavundo has several dozen *Castor* trees growing on his 10-acre Taita farm in Coast Province.

The seeds, leaves, and stems of *Castor* are poisonous to humans and livestock, although the leaves are claimed to be used as fodder for eri silkworms (*Philosamia cynthia ricini*) .[cx] The seeds contain the toxic protein ricin and hyperallergenic albumins, which can cause nausea, vomiting, abdominal pain, severe dehydration, and kidney and liver problems.[cxi] Refined ricin, created via a difficult and scientifically advanced process, has been used as a bio-weapon. Scientists at the USDA Agricultural Research Service are working to produce a genetically modified *Castor* variety that will eliminate the toxic compounds from the oil, thus reducing exposure in processing.[cxii]

5.2 Agronomy

5.2.1 Agronomic Parameters

The mean altitude of the 17 farms visited growing *Castor* where GPS data was taken was 1,690 meters; the median was 1,769 meters. The number of farms visited and the number of trees per farm were both too insignificant, and the management practices employed too random, to find any correlation between productivity and agro-ecological conditions.

Table 28: Agro-Climatic Parameters for *Castor*, from Literature and Kenya Survey

Agronomic Parameter	Range[cxiii]	Optimal[cxiv]	Kenya (from Survey)
Annual Temperature (°C)	15-39°C	20-30°C	Range – 14.2-24.2°C Mean – 18.6°C, Median 17.6°C
Annual Rainfall (mm)	400-2,000 mm	750-1,000 mm	Range – 615-1,801 mm Mean – 1,333 mm, Median – 1,038 mm
Altitude (m)	0-2,000 m	300-1,800 m	Range – 645-2,346 m Mean – 1,690 m, Median – 1,769 m
Soil	Well drained, loam that can tolerate moderate acidity.[cxv]		Loamy, sandy.

5.2.2 Pests and Diseases

Many pests are reported to affect Castor, including up to 50 species of insects, such as: grasshoppers, various larvae, capsid bugs, green stink bugs, lygus bugs, helopeltis, semi-looper (said to be the most devastating in India), capsule borer, tobacco caterpillar, jassids, white flies, and thrips.[cxvi]

Common diseases affecting *Castor* include: seed rot and seedling blight from various fungi and bacteria including *Fusarium, Rhizoctonia and Sclerotium*; charcoal rot, or blackening of the stem near the soil line, caused by the fungus *Macrophomina phaseolina;* cotton root rot, caused by the fungus *Phymatotrichum omnivorum*; leaf spot, which are light brown, circular spots, caused by the fungi *Cercospora ricinella* and *Alternaria recini* and bacterium *Xanthomonas ricinicola*; leaf rust, where leaves dry up, blacken and fall, caused by the bacteria *Pseudomonas* sp.; gray mold, where an entire cluster of leaves is covered in a prominent wooly mass of fungal growth, caused by the fungi *Botrytis ricini*; and capsule molds, where the seed capsules turn bluish to black, caused by the fungi *Alternaria* sp., *Penicillium* sp., and *Fusarium* sp.[cxvii]

Castor growing in the wild in South Nyanza Province.

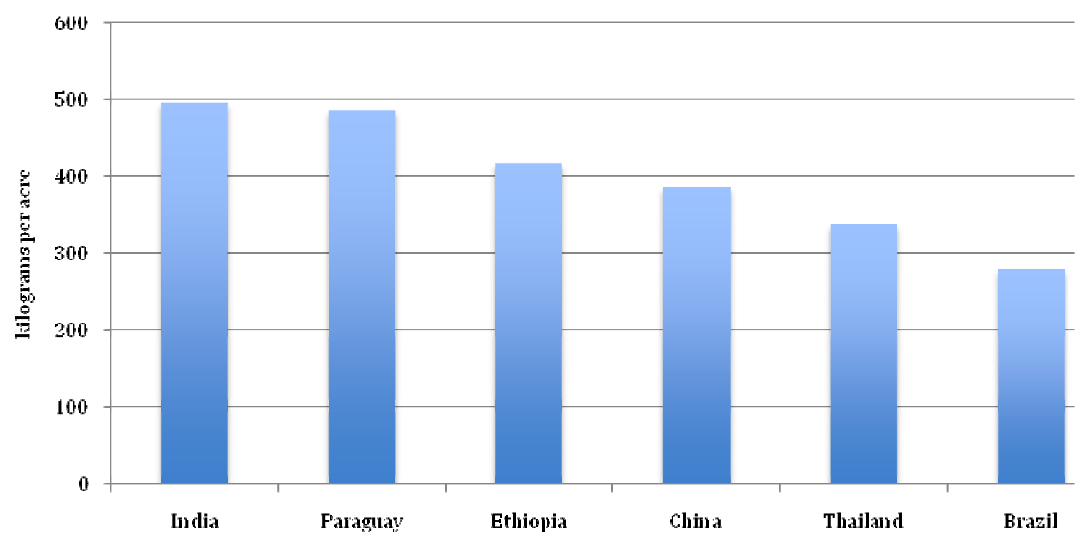
Only five out of the 21 farms visited that were growing *Castor* reported any pests or diseases associated with the crop. This included two reports of golden beetle, one of powdery mildew, three of caterpillars, and two of weevils. Only one farmer reported using any type of pest control, which included applications of ashes around the plant and on the leaves.

5.2.3 Yield

The average yield in the six largest *Castor* producing countries in the world in 2007 was 401 kilograms per acre (see Chart 19 for a comparison of yields per country).[cxviii] According to FAOSTAT, Kenya reported an average yield of 231 kilograms per acre in 2007, although it is hard to determine what this is based on, as there are few, if any, farmers currently growing *Castor* commercially.[cxix] Reports from India indicate yields as low as 350 kilograms per acre, which may be closer to reality for many smallholders in more marginal areas.[cxx] Irrigated *Castor* is reported to yield between 800 and 1,600 kilograms per acre.[cxxi] The oil content of the seeds ranges from 35-55%.[cxxii] Thus, one tonne of seeds will yield between 365 and 573 liters, factoring in *Castor* oil's density of 959.3 kilograms per tonne of oil.[cxxiii]

The Kenya Agricultural Research Institute (KARI) conducted research over a decade ago into the development of high-yielding local *Castor* varieties. According to KARI, the variety named "KC 4" was reported to yield 1,415 kilograms per acre, with seed oil content of 48.8%.[cxxiv]

Chart 19: *Castor* Yield per Acre in Six Largest Producing Countries, 2007



The number of farms visited during the survey and the number of trees per farm were both too insignificant, and the management practices employed too random, to draw any significant conclusions regarding yield. The mean yield of the 12 farmers who reported data was 0.836 kilograms per tree. The median yield was 0.5 kilograms per tree. Based on the small sample size, however, it is nearly impossible to extrapolate what the average yield might be for an acre of land. This is because the farmers may not have been keeping close records for what there *Castor* trees actually yielded given the lack of market, and the fact that individual *Castor* trees intercropped among other crops may not provide an accurate indicator of the productivity of the average tree grown within a monoculture or highly-managed intercropped plantation. For these reasons, we were unable to determine whether management practices or agro-ecological conditions many have had any affect on the yields of the surveyed farmers' *Castor*.

5.2.4 Management Practices

Propagation and Spacing

Castor is generally propagated by direct sowing about 6-8 centimeters deep, in rows spaced between 0.9-1.2 meters and spaced 0.2-0.6 meters in between rows, requiring 11-16 kilograms of seed per hectare planted.[cxxv] It is recommended that seeds be treated with 3 grams (per kilogram of seed) of Thiram, a fungicide, before planting to avoid root rot and Alternaria blight, especially in areas with low temperatures and high soil moisture at time of planting.[cxxvi] Seedlings will typically emerge within 7 to 21 days.[cxxvii] Most of the 21 *Castor*-growing farms visited during the survey had *Castor* spaced randomly throughout. Other reported spacing included: 1 x 1, 2 x 2, 3 x 3, 4 x 4, and 5 x 5 meters.

Castor is routinely intercropped in many parts of the world. Research from India recommends *Groundnut* as a suitable crop for planting with Castor, in ratios between 3:1 to 7:1 (*Groundnut*: *Castor*).[cxxviii] Rainfall may also affect productivity of *Castor* when intercropped. An experiment in Hyderabad, India in 2001-2002, a year of low rainfall, and 2002-2003, a year of heavy rainfall, found that *Castor* yields were only reduced by 16% when intercropped with abundant rainfall (as compared with a sole crop of *Castor* under the same conditions), while the yield dropped by over 37% during the drought year.[cxxix] The Philippines Council for Agriculture recommends *Castor* as one of the short-to-medium term species for growing in agroforestry systems involving food crops, trees, and nitrogen species.[cxxx] Two of the 21 *Castor* farms surveyed were growing it as a natural fence; the remainder had it intercropped with combinations of maize, beans, sorghum, potato, wheat, banana, cassava, peas, and mango.

Seed Varieties and Sources

There are both annual and perennial varieties of *Castor*. Fast growing, high-yielding, dwarf annuals are usually used for mechanical harvesting, while locally-adapted, perennial landraces are typically used among smallholders who establish and harvest by hand. There are at least three indigenous landraces of *Castor* in Kenya. They differ by the color of the seeds and the plant's root systems, and possibly by yield, but no information exists to confirm differences in yield. Seeds from these landraces are readily available from areas where it is growing in the wild and untended.

White *Castor* seed.

As mentioned above, KARI has worked to develop four local hybrid varieties of *Castor*, although they are not available for planting. High yielding hybrid varieties from overseas, mainly from India and Brazil, can be imported, although this approach may not prove economical due to the expense and logistical hurdles associated with importing seeds into the country. Fourteen of the twenty-one *Castor* farmers surveyed obtained seeds from locally growing wild or semi-wild trees. One reported obtaining seeds from KEFRI and another from an agricultural exhibit in Kisumu.

Weeding and Fertilization

It is recommended that *Castor* crops undergo two weedings, one prior to planting and the second during mid-growth.[cxxxi] A pre-emergent herbicide, such as Alachlor @ 1.25 kg/Ha or Trifluralin (dosage to be determined based on manufacturer's recommendations), may also be used.[cxxxii] Ample amounts of nitrogen, phosphorous, and potassium are needed for healthy productivity. Recommended treatment for soils poor in these nutrients are between 90-135 kilograms per hectare of nitrogen, 37-56 kilograms per hectare of phosphorous, and 15-19 kilograms per hectare of potassium.[cxxxiii] Precise treatments should be determined based on local soil fertility, but it is recommended that half of the nitrogen dosage and all of the phosphorous and potassium should be applied at planting, and the second half of the nitrogen side dressed between rows a week or two before cultivation.[cxxxiv] However, too much Nitrogen can cause excessive growth of vegetative matter with reduced seed production.

Castor seedpods before harvesting.

Sixteen of the 21 *Castor* farmers reported weeding at least one time per year, with most conducting two weedings annually. Only one farmer reported using any type of pest or disease control (ashes). No farmers applied synthetic fertilizer to *Castor*, although three reported using manure.

Harvesting

The crop matures in about 140-170 days depending on variety and agro-ecological conditions, with longer period in more ASAL areas.[cxxxv] *Castor* may be harvested mechanically, where the tree is cut by a combine and the seed sorted with a cylindrical harvester, or by hand, where the tree is left to produce year after year, but usually replanted every five years. Harvesting should occur when the seedpods are dry, but prior to the point where they begin shattering on their own.

5.3 Economics

The economics of *Castor* production is well understood in many parts of the world where production is high, such as India and China. A dynamic market exists for various grades of *Castor* oil, as is described in Section 5.1.3 above. Commercial *Castor* production in Kenya is virtually nonexistent despite the fact that the species is indigenous to the region.

Castor SVO sample.

As mentioned above, there are various types of high yielding hybrid *Castor* seeds that perform as annuals so need to be replanted every year. These are more suitable to larger mechanized plantations. The case presented below envisions the use of locally produced certified seeds that can produce for five years before being replanted, thus minimizing costs to small farmers. Of course, the yields from the non-hybrid perennials are generally lower than those of the more advanced seed types.

The analysis is based on costs of production for similar crops being grown by smallholder farmers in Kenya. Two scenarios are presented: a one acre monoculture plantation with 2,646 plants spaced 1.5 meters by 1 meter apart, and a fence spaced 0.5 meters around the perimeter of a one acre plot of land. Yield and price data is taken from estimates from other parts of the world where *Castor* is being produced.

5.3.1 Cost of Production

The following section analyzes the overall cost of production for each Castor plantation type. Table 29 below provides the breakdown of costs for a one-acre Castor plantation over ten years. It is assumed that five kilograms of seeds will be needed to establish and replant 2,646 trees, at a cost of Ksh 200 per kilogram. Planting will be done in the first and sixth years.

Planting and establishment equipment includes rope and stakes spacing out the plantation, jembes (hoes) and pangas (machetes) for clearing land, cutting weeds, and digging holes. Fertilizer and pest control equipment, such as shovels, buckets, and gloves, are also included in this line item. The total equipment cost is Ksh 4,900. A cost of ten percent is added every year thereafter for replacing worn out equipment. One half a kilogram of manure per tree will be applied every year at a cost of Ksh 1.1 per kilogram, which is based on the average cost of farmers surveyed in this study. We estimate 0.25 grams of pest and disease control chemicals will be required per tree per year at a cost of Ksh 2,000 per kilogram.

Four person/days of hired labor is included in the first year for land preparation and planting, plus an additional five person/days in year six. The daily wage is assumed at Ksh 250 per person/day, which is about 55% higher than the average wage paid by farmers interviewed in the survey. However, as a theoretical budget, we conservatively assume a higher wage. Two person/days is included each year for fertilization and two person/days per year for pest and disease control. Weeding is crucial to avoid competition with young trees in the first few years. The budget includes three person/days two times the first and sixth years for weeding the one-acre plot and one person/day two times each other year.

Two harvests are expected each year, following the rains. The harvesting will be done by hand using metal buckets to collect seedpods before they have fallen to the ground. Once the seeds are harvested, they will be sun-dried on tarps (Ksh 1,000 each) and then placed in 60-kilogram bags (Ksh 20 each). Three person/days two times a year will be required for harvesting.

Table 29: Cost of Production Over Ten Years, One-Acre Monoculture *Castor* Plantation

Years	1	2	3	4	5	6	7	8	9	10
Inputs (Ksh/acre)										
Seeds	1,000	0	0	0	0	1,000	0	0	0	0
Plant, Weed, Fertilizer, Pest Equip	4,900	490	490	490	490	490	490	490	490	490
Manure	1,455	1,455	1,455	1,455	1,455	1,455	1,455	1,455	1,455	1,455
Pest/Disease Control	662	662	662	662	662	662	662	662	662	662
Harvesting Equipment	500	100	100	100	100	100	100	100	100	100
Seed Processing	1,160	260	260	260	260	260	260	260	260	260
Inputs Sub-Total	9,677	2,967	2,967	2,967	2,967	3,967	2,967	2,967	2,967	2,967
Labor (Ksh/acre)										
Land Preparation	1,000	0	0	0	0	1,250	0	0	0	0
Planting	750	0	0	0	0	1,500	0	0	0	0
Fertilization	500	500	500	500	500	500	500	500	500	500
Pest Disease Mgmt	500	500	500	500	500	500	500	500	500	500
Weeding	1,500	500	500	500	500	1,500	500	500	500	500
Harvesting	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
Labor Sub-Total	5,750	3,000	3,000	3,000	3,000	6,750	3,000	3,000	3,000	3,000
Cost Total	15,427	5,967	5,967	5,967	5,967	10,717	5,967	5,967	5,967	5,967

Table 30 below provides the breakdown of costs over ten years for a Castor fence around the perimeter of a one-acre plot. It is assumed that 0.9 kilograms of seed will be needed to establish and replant 508 trees. The total equipment cost is Ksh 800 the first year and 10% of that every year thereafter. The amount is much lower than in the plantation budget, as it is expected that farmers will utilize equipment from their main crops to support the establishment and management of the fence crop. Manure costs are proportionate to the number of trees, but based on the same quantities as in the plantation model.

Two harvests are expected each year, following the rains. The harvesting will be done by hand using metal buckets to collect seedpods before they have fallen to the ground. Once the seeds are harvested, they will be sun-dried on tarps (Ksh 1,000 each) and then placed in 60-kilogram bags (Ksh 20 each). No hired labor is assumed for the fence budget, which is consistent with the current common practice among smallholder farmers growing similar crops.

Table 30: Cost of Production Over Ten Years, One-Acre Fence *Castor* Plantation										
Cost (Years 1-10)	Year 1	2	3	4	5	6	7	8	9	10
Inputs (Ksh/acre)										
Seeds	180	0	0	0	0	180	0	0	0	0
Plant, Weed, Fertilizer, Pest Equip	800	80	80	80	80	160	80	80	80	80
Manure	279	279	279	279	279	279	279	279	279	279
Pest/Disease Control	0	0	0	0	0	0	0	0	0	0
Harvesting Equipment	500	50	50	50	50	50	50	50	50	50
Seed Processing	1,020	122	122	122	122	122	122	122	122	122
Inputs Sub-Total	2,754	506	506	506	506	766	506	506	506	506
Labor (Ksh/acre)										
Land Preparation	0	0	0	0	0	0	0	0	0	0
Planting	0	0	0	0	0	0	0	0	0	0
Fertilization	0	0	0	0	0	0	0	0	0	0
Pest Disease Mgmt.	0	0	0	0	0	0	0	0	0	0
Weeding	0	0	0	0	0	0	0	0	0	0
Harvesting	0	0	0	0	0	0	0	0	0	0
Labor Sub-Total	0	0	0	0	0	0	0	0	0	0
Cost Total	2,754	506	506	506	506	586	506	506	506	506

5.3.2 Prices, Markets and Revenue

Castor oil's long list of applications spurs a robust international market. In 2007, over 1.4 million tonnes of Castor seeds, amounting to approximately 560,000 tonnes of Castor oil, were produced in over 30 countries (see Table 31). The average producer price in the six largest Castor-producing countries in 2007 was $257 per tonne of seed.cxxxvi The March 2009 spot price for Castor seed on India's National Commodities & Derivatives Exchange (NCDEX) was $405 per tonne.[cxxxvii]

Table 31: Castor Yield, Production (2007) and Producer Price (2006) from Six Largest Producing				
Country	Yield (kgs/acre)	Area Harvested (acres)	Production (tonnes)	Producer Price (US$/tonne)
India	496	2,124,200	1,053,603	$377
China	387	543,400	210,296	$325
Brazil	280	403,929	113,100	$207
Ethiopia	419	35,815	15,006	$246
Paraguay	486	24,700	12,004	$153
Thailand	338	32,446	10,968	$234

As mentioned above, Kenya has virtually no domestic production of *Castor* seeds or oil. In 2006, Kenya imported 428 tonnes of *Castor* oil at a price of $1,063 per tonne.[cxxxix] Personal experience of the authors indicates that farmers will collect seeds growing on and around their farms for between 10 and 15 Ksh per kilogram. For purposes of this analysis, we assume a farm-gate price of Ksh 20 per kilogram, which is roughly equivalent to the average producer price from the top six *Castor* producing nations referenced above.

As shown in Table 32, we consider three potential yields in the analysis: low, medium, and high. The low and high yields are equivalent to the low and high yields of the top six Castor producing nations, and the medium yield is equal to the average yields of all six nations. The yield for the fence plantation is based on the relative number of trees per acre compared with the monoculture plantation (508 instead of 2,646, or 19.2%), less 20% further due to lower expected yields with tighter spacing and thus greater competition for moisture and fertility.

Table 32: Revenue Over Ten Years, One-Acre Monoculture and Fence *Castor* Plantations		
Revenue	Plantation	Fence
Yield Low (kg/acre)	280	43
Yield Med (kg/acre)	401	62
Yield Hi (kg/acre)	496	76
Farm-Gate Price (Ksh/kg)	20	20
Revenue Low Total	5,600	860
Revenue Med Total	8,020	1,240
Revenue Hi Total	9,920	1,520

5.3.3 Net Margins, Break-Even Analysis and Internal Rates of Return

The net margin for the low yield monoculture plantation is negative. If medium or high yields are achieved, we estimate that the net margin is positive in all but the year of planting: the first and sixth (see Table 33). The fence plantation operates at an annual profit in all but the first year for all three-yield scenarios (see Table 34). The monoculture plantation breaks even on the investment in year five for the medium yield and year three for the high yield (the low yield monoculture scenario never breaks even). For fence, the low scenario breaks even in year eight, the medium and high scenarios begin turning an overall profit in years four and three, respectively.

Table 33: Net Margin Over Ten Years, One-Acre Monoculture *Castor* Plantation										
Net Margins Plantation	1	2	3	4	5	6	7	8	9	10
Low (Ksh/acre)	-9,827	-367	-367	-367	-367	-5,117	-367	-367	-367	-367
Med (Ksh/acre)	-7,407	2,053	2,053	2,053	2,053	-2,697	2,053	2,053	2,053	2,053
High (Ksh/acre)	-5,507	3,953	3,953	3,953	3,953	-797	3,953	3,953	3,953	3,953

Table 34: Net Margin Over Ten Years, One-Acre Fence *Castor* Plantation										
Net Margins Fence	1	2	3	4	5	6	7	8	9	10
Low (Ksh/acre)	-1,919	329	329	329	329	69	329	329	329	329
Med (Ksh/acre)	-1,539	709	709	709	709	449	709	709	709	709
High (Ksh/acre)	-1,259	989	989	989	989	729	989	989	989	989

Table 35 shows the internal rate of return (IRR) for the two different plantation investments at all three yields. The high yield scenario shows a very attractive return for both plantation types and the medium yield is also attractive for the fence plantation. Neither low case is feasible.

Table 35: 10-Year Internal Rates of Return One-Acre Monoculture and Fence *Castor* Plantations			
Internal Rate of Return (10 years)	Low	Medium	High
Plantation	loss	15.11%	66.58%
Fence	7.48%	43.01%	77.19%

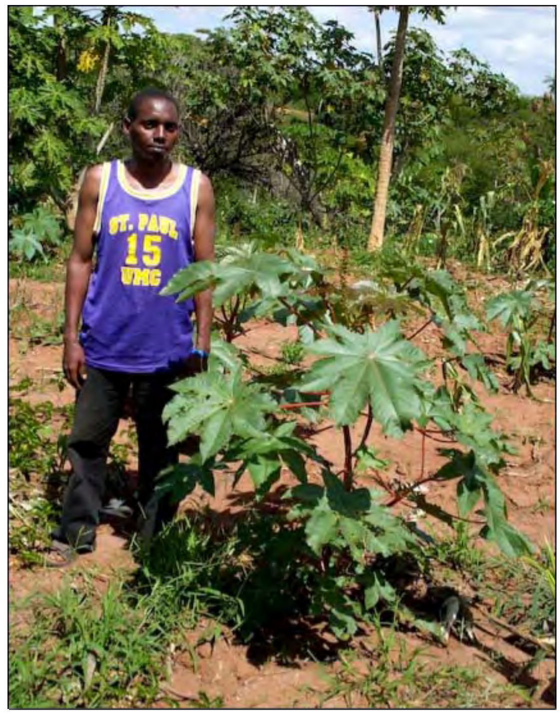
5.3.4 Opportunity Cost

To evaluate the attractiveness of the investment based on IRR, it is helpful to compare these returns to those of a money market account or equity investment over the same period. A money market account yielding 2% interest over 30 years yields an IRR of over 15%. An equity investment that averages 5% returns annually would yield an IRR of over 27%. Thus, when considering the relative safety of a money market account, it is hard to imagine investing in a more risky oilseed and timber plantation. However, a more realistic assessment of the value of the investment from the perspective of a small to medium-sized African farmer is to consider the opportunity cost in terms of alternative uses of the land.

5.4 Production in Kenya

5.4.1 Historic and Current Activities

Despite its local origins, and the global demand for *Castor* oil, Kenya does not currently produce any on a commercial scale. At least three local varieties grow wild throughout the country, as well as on and around farms. Some farmers plant it to prevent soil erosion, and for other non-commercial purposes. A few individuals interviewed as part of this study reported crushing the oil for use in homemade lotions.

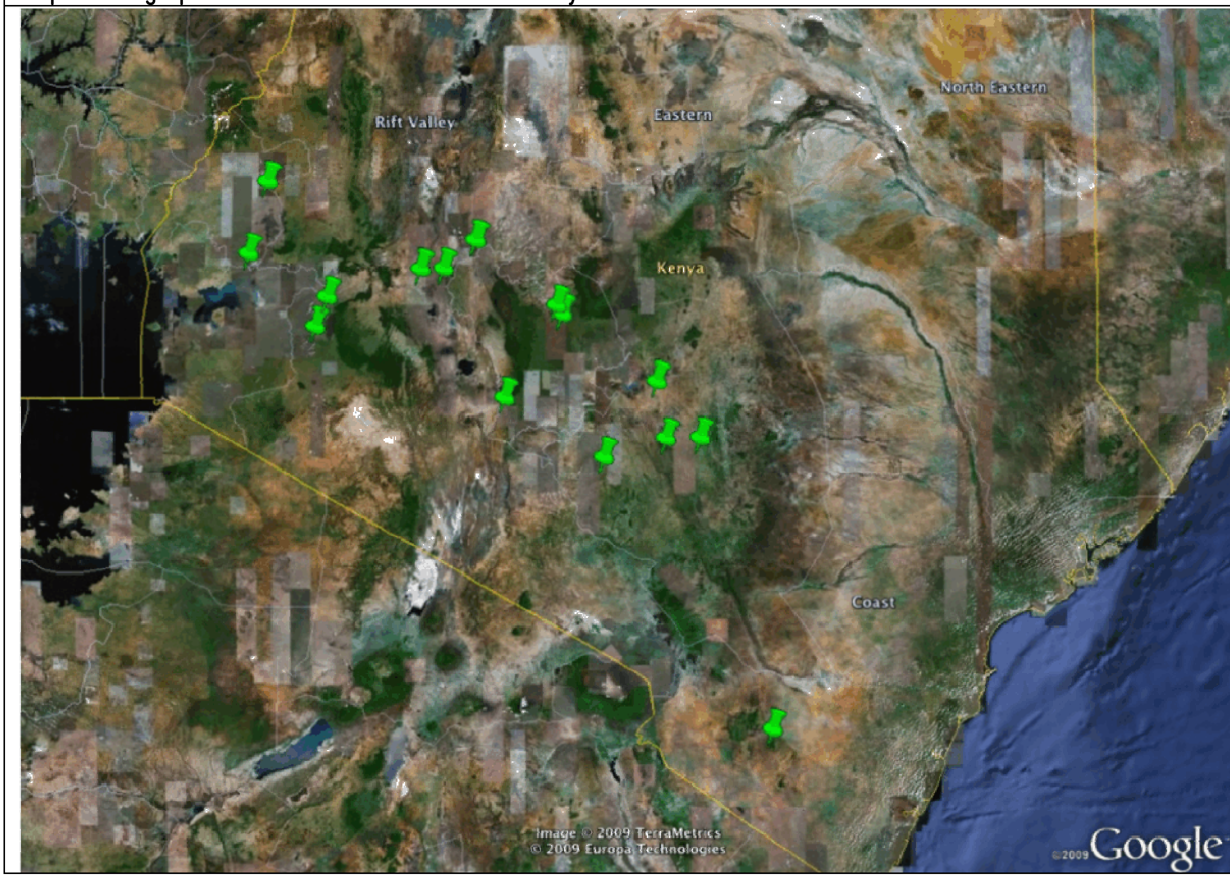


One of twenty, three year-old *Castor* trees growing on the Kitui farm of Beatrice Mutetuya Mutisya.

Many remember widespread interest in cultivating *Castor* in the 1970s and 1980s that resulted in large part from a governmental program promoting the crop. As a result, large numbers of farmers planted *Castor* in their fields, but the program quickly collapsed due to the lack of any established market for buying and processing the seeds. With global demand for *Castor* steadily increasing, an opportunity currently exists to restart a domestic *Castor* production industry, which could market the oil for a number of uses, including biofuels, both within Kenya and for export.

We found *Castor* growing in all of the six regions covered by the survey, although with little if any effort towards commercial production (see Map 10). Only 21 of the 397 farms visited contained *Castor*. Every farm growing *Castor* was either using it as a natural fence or intercropped with a variety of food crops. The mean number of trees per farm was 37 and the median 18. None of the farmers reported selling any of the seeds harvested from the *Castor* trees, nor did they indicate any available market for *Castor* seeds. The following map indicates the locations where enumerators observed *Castor* growing on and around farms throughout the field survey.

Map 10: Geographic Locations of *Castor* Farms Surveyed



5.4.2 Mapping and Overall Suitability

In addition to identifying the most attractive plantation type, we have also attempted to locate the optimal geographic locations to focus investment. To accomplish this we incorporated three categories of data into the following maps: agronomic suitability, market accessibility, and potential conflicts with existing land uses, including food, cash crops, and gazetted areas.

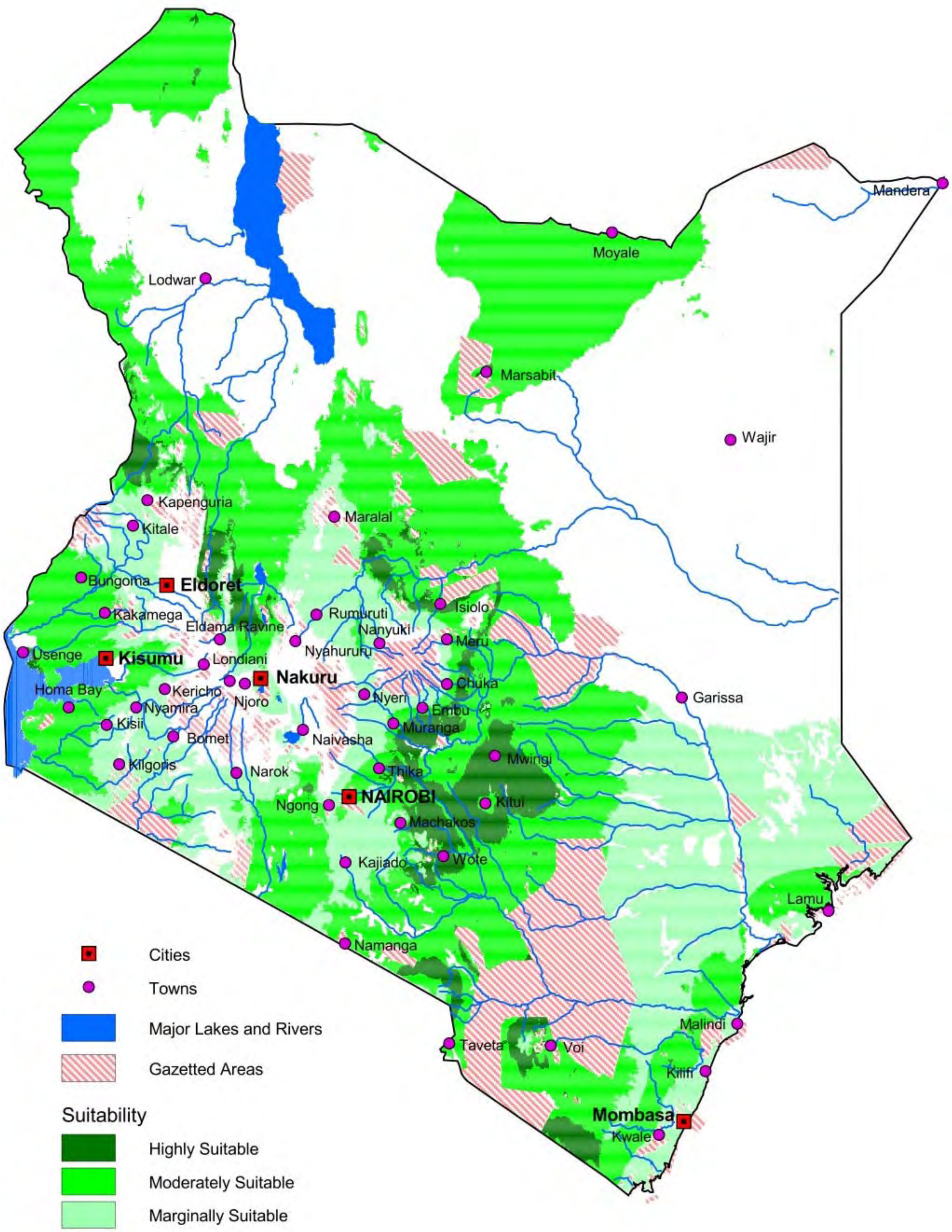
The *Castor* suitability map (Map 11) utilizes the agronomic conditions contained in Table 36 and described in more detail in Section 5.2.1. Suitability is divided into areas that are considered highly, moderately, and marginally suitable according to the range and optimal growing conditions listed above. 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.

Table 36: Range and Optimal Agronomic Suitability for *Castor*		
Agronomic Parameters	Range	Optimal
Annual Temperature (°C)	15-39°C	20-30°C
Annual Rainfall (mm)	400-2,000 mm	750-1,000 mm
Altitude (m)	0-2,000 m	300-1,800
Soil	Loamy, sandy.	

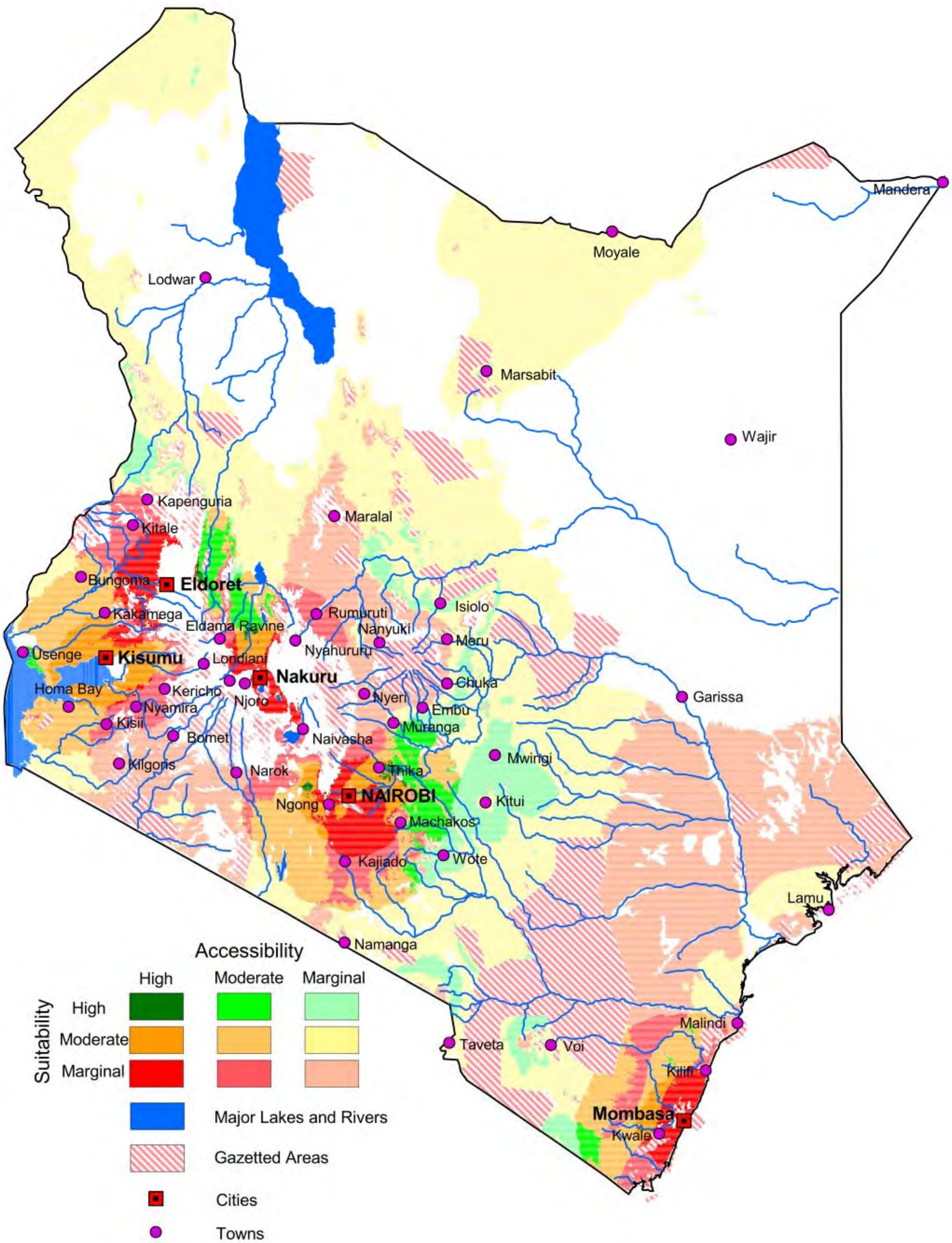
For market accessibility, we created two maps. Map 4 above shows accessibility to major cities, including Eldoret, Kisumu, Mombasa, Nairobi, and Nakuru. Map 5 above shows accessibility to major towns throughout the country. The idea was to depict accessibility for large-scale commercial investments in the first map and smaller-scale projects in the second. For both maps, accessibility is a factor of the time it generally takes to travel to the nearest city or town, according to existing road network, slope, land-use, land-cover, urban centers, and rivers and lakes.

We then combined the maps to show both suitability and accessibility together (see Maps 14 & 15). These maps use a colored grid to depict and overlay three grades of suitability – highly, moderately, and marginally – with the three grades of accessibility. A final set of maps overlay existing food and cash crop growing areas with those locations that are potentially suitable for the select oilseed crop, in this case *Castor* (see Maps 16 & 17).

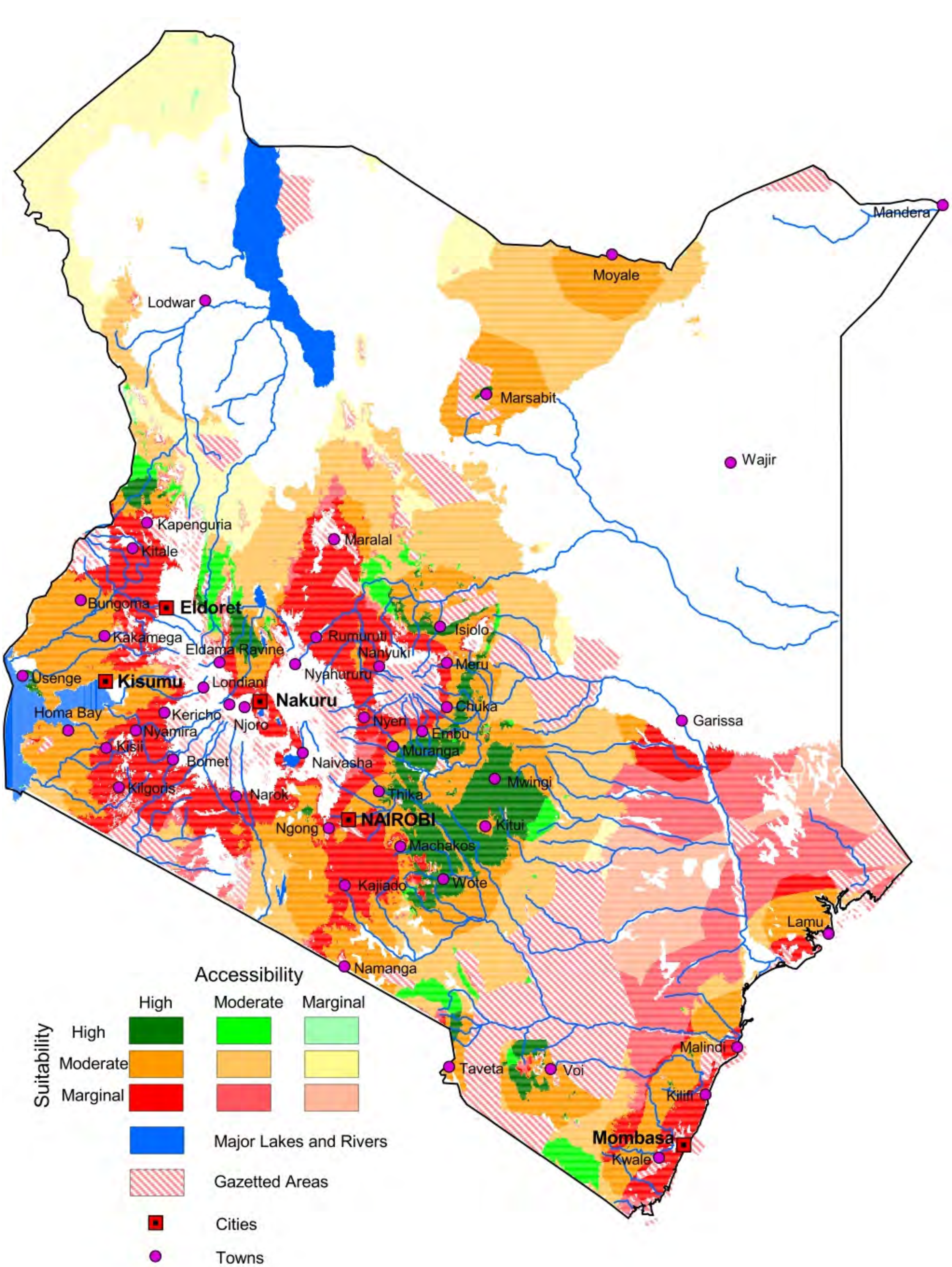
Map 11: Agronomic Suitability of *Castor* in Kenya



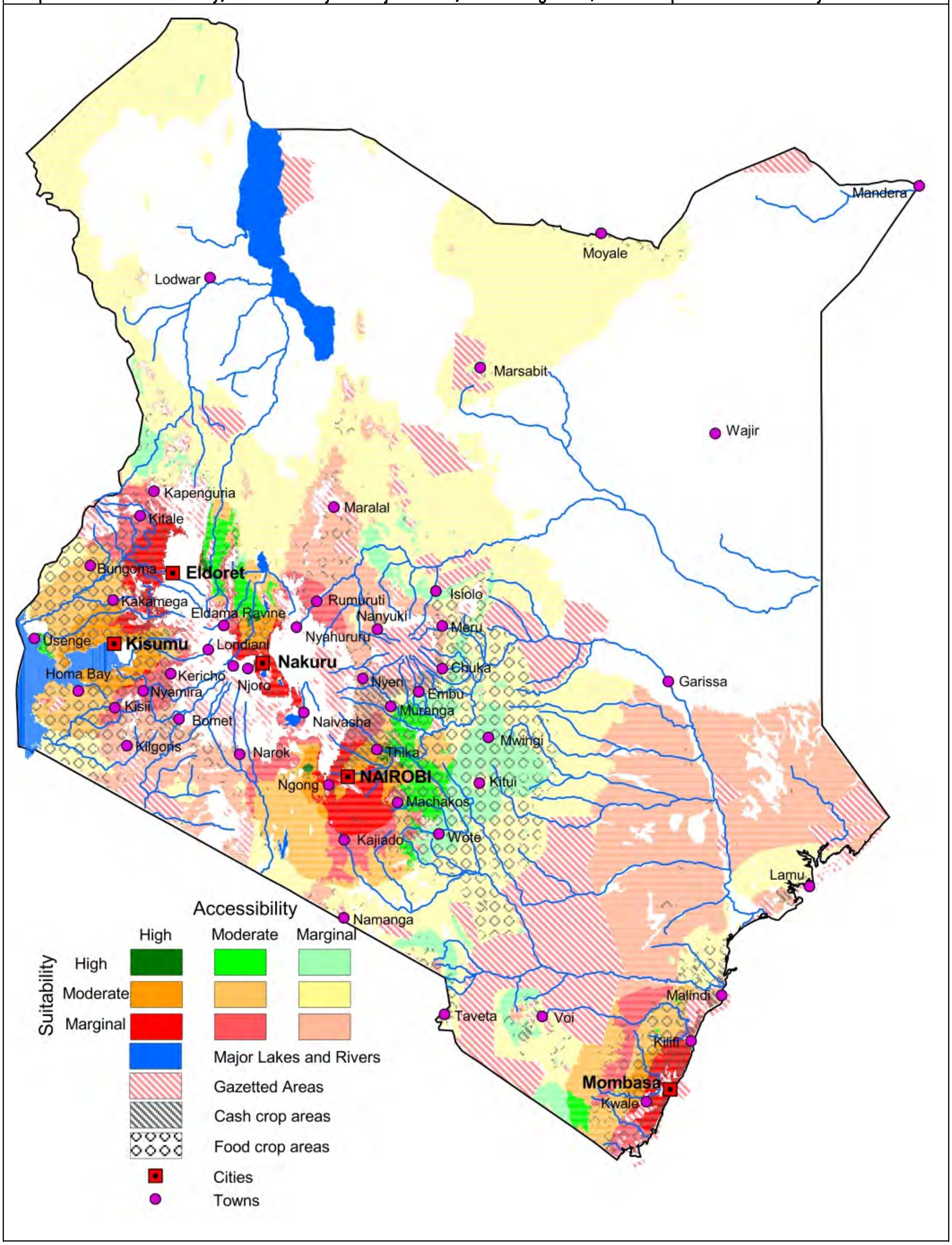
Map 12: *Castor* Suitability & Market Accessibility to Major Cities in Kenya



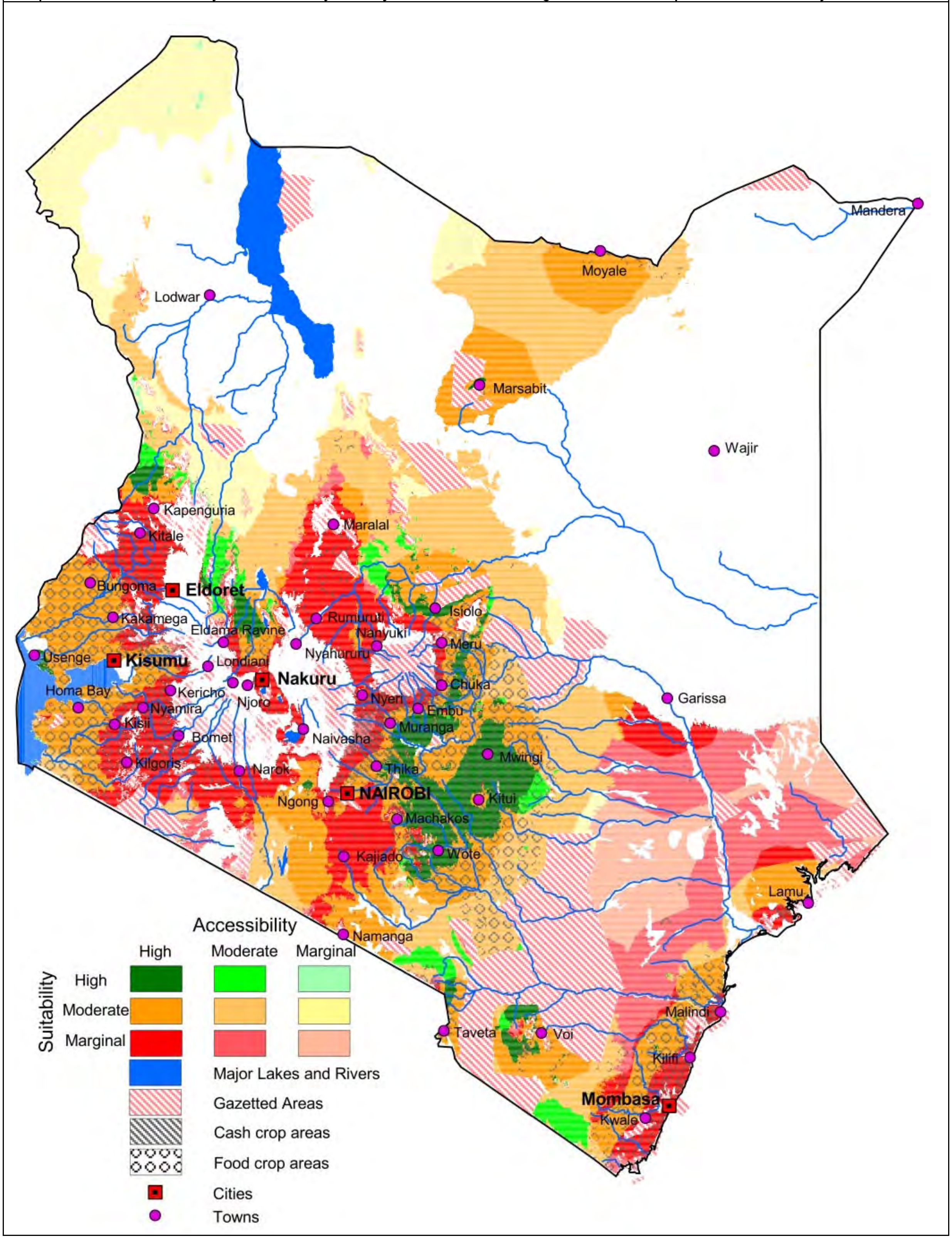
Map 13: *Castor* Suitability & Market Accessibility to Major Towns in Kenya



Map 14: *Castor* Suitability, Accessibility to Major Cities, & Existing Food/Cash Crop Land-Use in Kenya



Map 15: *Castor* Suitability, Accessibility to Major Towns, & Existing Food/Cash Crop Land-Use in Kenya



5.5 Outlook, Potential and Obstacles

The revival of *Castor* production in Kenya could be a boon to farmers and others. The crop is suitable to be grown throughout the country, a mature market exists both domestically and internationally, and processors are waiting to develop the industry. Even if the market for liquid biofuels is unattractive, alternative markets exist for *Castor* oil. Kenya alone imports about 400 tonnes of high-quality *Castor* oil per year. That amounts to about 1,000 tonnes of seed, which would require between 2,260 and 4,200 acres to grow, which is equivalent to about Ksh 15-20 million in new farmer income.

Of course, there are challenges to successfully launching a new Castor production industry in Kenya. First and foremost is the lack of experience growing and processing the crop. Trials must be established by private sector interests and research institutions to create local knowledge on agronomy, as well as to create reliable sources of high-quality planting material. Local processers must also import the machinery required to process high-quality Castor oil.

6. Croton

Croton megalocarpus (*Croton*) is a pan tropical pioneer species that grows in cleared parts of natural forests, forest margins, and as a canopy.[cxl] It is indigenous to Eastern and Southern Africa, but very closely resembles other *Croton* species growing throughout Africa.[cxli] Although no formal tree population census has been conducted for *Croton* in Kenya, anecdotal evidence suggests millions of trees growing in the wild and on farms throughout the country. Various efforts to use *Croton* for reforestation projects are also underway throughout the country, as we explain further below.



Left: John Mutuku showing his 12-year-old *Croton* on his six acre Nyeri farm, Central Province. Middle: Nineteen year old *Croton* surrounding homestead in Yatta, Eastern Province. Right: *Croton* seedpods, or fruits, collected from 19-year-old *Croton* fence on Anthony Njonge Gitau's five-acre Kibwezi farm, Eastern Province.

6.1 Overview

6.1.1 Names

Scientific Name: *Croton megalocarpus* Hutch.

Common Names: Croton (English), Mbula, Nkulumire (Luganda), Msenefu, Musine (Swahili); Nyapo (Boran), Nyaepo (Duruma), Nyaap'po (Gabra), Muyama (Giriama), Muthulu (Kamba), Mukinduri (Embu/Meru/Kikuyu), Musine (Luhya), Olmerguet (Maasai), Masineitet (Nandi), Marakuet (Samburu), Mkigara (Taita), Ortuet (Tugen).[cxlii]

6.1.2 Description

Croton is a hardy, fast-growing deciduous tree with distinctive layering of branches, growing into a straight bole of between 6-36 meters.[cxliii] The crown is rather flat, providing light shade. It has a dark grey or pale brown, rough, and longitudinally cracking bark with a strong pepper-like spicy odor.[cxliv] The leaves are variable, long, oval-shaped, and pointed up to 12 centimeters, but often much smaller. The dull green, upper surface of the leaves contrasts with the pale, silvery underside.[cxlv] Flowers are monoecious or dioecious, conspicuous, and short lived. *Croton* mostly include pollen-producing male reproductive organs, with a small number of female flower buds at the base of the stalk opening. The flowers form after heavy rains in small pale, yellow hanging inflorescences of about 25 centimeters in length. The grey, woody, oboviod fruits measure about 2-4 by 1.5-3 centimeters in size.[cxlvi] Each fruit contains three flattened, grayish-brown seeds.[cxlvii]

Croton has yellowish to brownish heartwood, sometimes with dark brown to black streaks near the center of the log. Its sapwood is not clearly differentiated. It is medium texture, straight grained and easy to work with, but splits badly and is generally not durable. It has an unpleasant smell when freshly cut and its sawdust has been reported to irritate the nose and throat.[cxlviii]

Of the 73 farms visited that were growing *Croton*, measurements were taken at 38 farms. The following table contains the mean and median height and number of branches, separated by age class of the trees. Very few trees were fruiting while the survey was being conducted, so no data is available.

Ritah Chawles Matteka standing alongside a ten-year-old 120-tree *Croton* fence on her 10-acre farm in Nzaui District, a semi-arid area of Eastern Province.

Table 37: Physical Characteristics of *Croton* Observed in Survey						
	Age		Height (meters)		# of Branches	
	mean	median	mean	median	mean	median
Age 0-10 Years	4.4	3.5	12.74	9.83	9.11	9.83
Age 11-20 Years	13.2	12.5	19.93	23.0	10.51	9.58
Age 21-30 Years	27.7	25	26.73	26.42	11.29	10.06

6.1.3 Uses

Croton is a multi-purpose tree that provides a wide range of direct and indirect uses and services.[cxlix] Its timber is commonly used for making agricultural implements, in building construction, joinery and furniture, and for provision of posts and poles for fencing.[cl] Its wood is termite resistant and quite strong, making it suitable for light and heavy general construction and flooring parquets.[cli]

Croton seeds produce inedible oil that is suitable for biofuel. *Croton* is also used for firewood and charcoal.[clii] However, its smoke is reported to cause irritation of the eyes and an unpleasant odor.[cliii] Well-dried *Croton* nuts are reportedly used in some areas together with charcoal in cooking stoves.[cliv]

The leaves, seeds, bark, roots, and wood extracts from *Croton* are used in a variety of human and veterinarian medicines, including the treatment of stomach ailments, malaria, wound clotting, and pneumonia.[clv] Bark decoction is used as a remedy for worms and whooping cough.[clvi] Pharmacology studies on biochemical constituents of *Croton* extracts show that they may have anti-cancer and anti-ulcer properties.[clvii] Various academic institutions are undertaking pharmacological studies to evaluate potential of *Croton* for medicinal uses, toxicity, and formulations for *Croton* seed meal for animals.[clviii] Claims that *Croton* species have high potential for production of essential oils are being investigated as well.[clix]

Rose Kaluki Mutua and her children standing under the shade of a Croton tree on her five-acre farm in Masinga District, Eastern Province.

Croton seed meal has very high protein content and is used for poultry feed, albeit with limited knowledge on feed formulations and its effect on the productivity and long-term health of birds.[clx] The presence of a potentially toxic substance called phorbol in the oil necessitates the need for epidemiological tests to determine any adverse affects on animals fed Croton seedcake. Leaves, and sometimes seeds are used as fodder for animals especially during the dry season in Kenya. *Croton* is also classified as an important honey-producing tree due to the forage it can provide bees.[clxi]

Croton's flat crown and horizontal layers of branches, it is useful in providing shade and serving as windbreak. *Croton* is also used for erosion prevention, as an ornamental, and for marking boundaries.[clxii] Its leaves have high nitrogen and phosphorous, acting as a source of mulch, especially in coffee plantations. Although short-lived, the conspicuous flowers are good ornamentals. Because the tree is not browsed due to its high purgative properties, it serves well as a natural fence.[clxiii]

Most of the products from *Croton* such as firewood, charcoal, poles, timber, and medicinal extracts are processed and sold locally. Firewood, when it is not used in households for cooking and house warming, is sold to hotels and tea curing factories. Simple traditional kilns are used to carbonize wood into charcoal, which is sold at about Ksh 400-600 per 35-kilogram bag. Medicinal extracts from *Croton* are sold in the local markets in raw form.

Mature *Croton* trees provide a boundary and protection for the maize, beans, and potatoes Peterson Mwaji grows on his three-acre farm in Nyeri District, Central Province.

6.1.4 Environmental Impacts

Croton trees can have a range of positive and negative environmental impacts on soils, water, and air. As an indigenous species planted in homesteads, community centers and marketplaces, *Croton* provides shade and shelter and acts as a windbreaker.[clxiv] Its relatively open-crown at maturity allows sufficient penetration of sunlight to the ground thus minimizing competition for sunlight with food crops and making it an excellent agroforestry species.[clxv]

Mature trees have deep taproots, which access fertilization to augment soil nutrients, while root exudates enrich soil with minerals and leaf litter rich in nitrogen, phosphorus, and organic carbon.[clxvi] *Croton* trees improve and stabilize soil through water retention and erosion retardation, thus minimizing the loss of valuable topsoil and the siltation of rivers and lakes.[clxvii] It also contributes to biodiversity enrichment by increasing birdlife species and butterfly farming for export by feeding caterpillars with leaves.[clxviii]

The potential for carbon sequestration from *Croton* is high due to their longevity. In some communities, it is not planted close to houses due to negative cultural beliefs.[clxix] They are also reported to have allelophatic effect on striga, a weed with adverse effects on maize. *Croton* trees trigger germination of striga although it does not survive in the absence of a host.[clxx]

6.2 Agronomy

6.2.1 Agronomic Parameters

Croton is indigenous to Eastern and Southern Africa and is commonly found as a dominant upper story tree within evergreen rainforests, riverine gullies, and semi-arid and sub-humid highlands. *Croton* is widespread throughout a wide range of biophysical limits in Kenya (see Table 38) including areas as ecologically diverse as Kakamega, Nairobi, Nyeri, Samburu, and Taita.[clxxi] It can be cultivated near homesteads, in fallow cropland, swamps and watercourses; it is suitable for intercropping with shade loving species, e.g. coffee, and it is suitable as a live fence or boundary.[clxxii]

Fruiting four-year-old *Croton* in Masinga District, Eastern Province.

The tree flowers at the end of April and early May. After pollination by bees, fruit development takes several months, producing mature seeds in October through December in central and northern Kenya, and in January through February in western Kenya.[clxxiii]

The optimal conditions for *Croton* seed production can be deduced from current areas of highest distribution, such as Kakamega, Nyeri, and the high altitude parts of the lake basin region. The tree tends to thrive in agro-climatic areas that are bimodal in rainfall, with cool, humid temperatures. Fruiting is prolific in areas where rainfall is not continuous or heavy. Optimal performance in the Mt. Kenya region is observed in middle level altitudes of places like Nyeri Township. In Western Kenya, the area around Kakamega are suitable, while in the Lake basin, optimal conditions for fruiting include the high altitude regions near Rachuonyo district.[clxxiv]

Table 38: Agro-Climatic Parameters for Croton, from Literature and Kenya Survey[clxxv]

Agronomic Parameter	Range	Optimal	Kenya (from Survey)
Annual Temperature (°C)	11-26°C	16-22°C (cool, semi-humid)	Range – 13.7-22.9°C Mean – 19.9°C, Median – 20.5°C
Annual Rainfall (mm)	800-1,900 mm	1,000-1,400 mm	Range – 632-1,816 mm Mean – 1,059 mm, Median – 952 mm
Altitude (m)	1,200-2,450 m	1,200-1,600 m	Range – 942-2,382 m Mean – 1,485 m, Median – 1,466 m
Soil	Light, deep, well-drained soils		Loamy, sandy

6.2.2 Pests and Diseases

There is limited information available on pests and diseases affecting *Croton*, although there are reports of *Ambrosia* beetle and the insect *Scolytidae* preying on it, especially at altitudes of 1,300-2,100 meters.[clxxvi] It is also reported to have an allelophatic relationship with *Striga* weed by triggering their germination, but is not parasitized by it.[clxxvii] Its wood is vulnerable to attack by decay and stain fungi.[clxxviii]

According to the Kenya survey, only a small number of farmers reported any pests or diseases associated with the Croton trees growing on their farms. This included two reports of red spider mite, four of powdery mildew, and several reports of caterpillars. One farmer reported using a chemical pesticide to control caterpillars, but did not recall the name of the chemical applied.

6.2.3 Yield

Croton trees seed prolifically during October-December in central and northern Kenya, and in January-February in western Kenya.[clxxix] Several factors influence yield: frequency of flowering, number of spikes, number of female flowers per spike, number of seeds per fruit, and seed weight.[clxxx] Currently, there is scant information on yield per tree because of a historical lack of demand for the seeds. However, the potential yield of mature trees has been assessed at about 25 kilograms per year, with some projections as high as 50 kilograms per year.[clxxxi] A systematic study is needed to determine yields under different growing conditions and within varied agro-ecological zones.

Seeds collected by Stephen Muehiri from a 19 year old *Croton* fence of about 60 trees in Yatta District, Eastern Province.

6.2.4 Management

Croton has high potential of improving rural livelihoods through proper tree husbandry. More systematic research needs to be undertaken to determine the best agronomic and silvicultural practices, value addition of the multiple products that can be produced from the tree, and development of a marketing strategy, especially for the emerging biofuel industry. It is fast-growing tree in high potential areas, but can also survive in harsh climatic conditions and is not browsed by animals.

Propagation and Spacing

Direct sowing is the most viable and recommended propagation method for *Croton*, although seedlings and cuttings are also used.[clxxxii] Treatment of the seeds before sowing is not necessary. The seeds germinate within 35-45 days.[clxxxiii] The species regenerates well through seedlings and may become invasive under favorable conditions. In some communities, *Croton* is not planted close to the house due to cultural beliefs. Of the farmers growing *Croton* visited during the survey, 55% used seeds, 42% used seedlings, and 3% could not recall which propagation method they used. Fifty-three percent of the farmers surveyed reported using wild seeds for planting, while 14% reported obtaining seeds from neighbors and 10% from KEFRI or an established nursery. The remaining 23% did not report where they obtained planting material.


Croton seedlings being grown on a farm in Kakamega District, Western Province.

Silvicultural and management practices are generally not given much attention because most *Croton* trees are not cultivated as a plantation crop. Most farmers spaced trees randomly throughout the farm to be used as a natural fence or around the home compound. *Croton* is a highly suitable agroforestry species. It provides a wide range of environmental and economic services in areas where it is planted, such as scattered homesteads, border spaces, home gardens, fallow cropland and farmlands.

Seed Varieties and Sources

Croton seeds for planting are collected by farmers and trained KEFRI seed collectors from high quality trees growing on farmlands, which KEFRI mark and track for future use as seed sources. The seeds are then processed in KEFRI labs for viability before storage in cold rooms. Proper seed handling, processing and storage enhance their quality and ultimate survival rate.

Irrigation, Pruning, Fertilization and Pests/Disease Control

Trees are generally not given any fertilizer or water after planting, but some water is usually given during planting and a minority of farmers reported using manure or compost occasionally. It coppices well when pruned young although intensive pruning tends to retard fruiting.[clxxxiv] It tolerates lopping and pollarding.[clxxxv] There are no reports of significant problems with pests and diseases.

Harvesting

Unlike most other biofuels feedstocks, *Croton* seedpods simply drop when ripe and can be caught in inverted "umbrellas," or simply raked together and picked up.[clxxxvi] Seeds are usually extracted from the fruit by cracking the shell with a hammer, stone or dehulling machine, giving an average of about 1,700 seeds per kg. They are sun-dried to 5-9% moisture content and can be stored up to one year at 3ºC.

Croton fruits and seeds from a 25-year-old fence planted on Joshua Webo Luvale's farm near Kakamega, Western Province.

6.3 Economics

There is limited empirical data on the economics of growing *Croton* as either a biofuel or timber crop. As a result, we have designed a theoretical model to test *Croton's* value from the grower's perspective. The assumptions underlying the model are based on observations of growth and yield characteristics from mature *Croton* trees growing throughout Kenya by expert foresters from KEFRI, as well as from the scientific literature. The model analyzes two plantation types and four growing scenarios, each on one acre of land. The first is a monoculture plantation with 160 trees spaced 5 by 5 meters apart. The second type involves a living fence or hedge of 72 trees grown 3.5 meters apart along the outer perimeter of the plot. Both plantation types are considered for their value if grown strictly for oilseeds or if grown for both oilseeds and timber.

Croton SVO sample.

6.3.1 Cost of Production

The following section analyzes the overall cost of production for each plantation type both with and without timber. Table 39 below provides the breakdown of costs for a one-acre monoculture plantation over ten years. We assume that 160 seedlings will be needed to establish and replant 144 trees, at a cost of Ksh 25 per seedling. Of course, larger plantations could reduce costs by producing their own seedlings in a nursery. We assume that smaller farmers with just a few acres or less will find it more cost effective to simply purchase seedlings from a certified supplier, like KEFRI.

Planting and establishment equipment includes rope and stakes for laying out the spacing in the plantation, jembes (hoes) and pangas (machetes) for clearing land, cutting weeds, and digging holes. Pruning saws are also included in this line item. We assume that this equipment, which will be used for land preparation, establishment, weeding and pruning, will only be needed for the first few years, so it is not a recurring cost. The total planting and establishment equipment cost is Ksh 7,400. Fifteen person/days of hired labor at Ksh 250 per man/day is included for land clearing, ploughing, and harrowing. Another six person/days is included for planting.

Fertilizer costs include equipment, such as shovels and buckets, and the cost of the manure itself. Five kilograms of manure per tree will be used in the first year and 2.5 kilograms per tree every year thereafter. We estimate a cost of Ksh 1.1 per kilogram of manure, which is based on the average cost of farmers surveyed in this study. Four person/days of labor is included for fertilizer in the first year and two person/days every year thereafter.

Pest and disease control costs include equipment, such as gloves and sprayers, plus the cost of pesticide. We estimate three grams per tree per year will be required at a cost of Ksh 2,000 per kilogram. Three person/days of labor is included for pest and disease management in the first year and two every year thereafter.

Weeding is crucial to avoid competition with young trees in the first few years. The budget includes eight person/days two times a year for weeding the one-acre plot. Pruning is also important in the first few years to ensure proper tree growth and seed production over the long term. Five person/days per year for the first three years is included in the budget for pruning.

The harvesting will be done by hand using metal buckets to collect seeds that have fallen to the ground. We estimate four buckets will be needed for the first four years, with 10% maintenance/replacement costs included, and then another two buckets every three years thereafter until the trees are mature. Once the seeds are harvested, they will be sun-dried on two tarps (Ksh 1,000 each) and then placed in 60-kilogram bags (Ksh 20 each) and stored in a small shelter built out of local materials (Ksh 1,000). The labor required for harvesting increases with yield. The first significant harvest in year two will require 12 person/days. By year 10, 40 person/days will be required.

Table 39: Cost of Production Over Ten Years, One-Acre Monoculture *Croton* Plantation

Years 1-10	1	2	3	4	5	6	7	8	9	10
Inputs (Ksh/acre)										
Seedlings	4,000	0	0	0	0	0	0	0	0	0
Plant/Estab Equip	7,400	0	0	0	0	0	0	0	0	0
Fertilizer	4,670	935	935	935	935	935	935	935	935	935
Pest/Disease	2,216	416	416	416	416	416	416	416	416	416
Harvesting Equip	0	2,000	200	200	1,000	200	200	1,000	200	200
Seed Processing	0	3,060	320	440	580	720	900	1,140	1,240	1,320
Inputs Sub-Total	19,286	6,411	1,871	1,991	2,931	2,271	2,451	3,491	2,791	2,871
Labor (Ksh/acre)										
Land Preparation	3,750	0	0	0	0	0	0	0	0	0
Planting	1,500	0		0	0	0	0	0	0	0
Fertilization	1,000	500	500	500	500	500	500	500	500	500
Pest Disease Mgmt	750	500	500	500	500	500	500	500	500	500
Weeding	4,000	4,000	4,000	0	0	0	0	0	0	0
Pruning	1,250	1,250	1,250	0	0	0	0	0	0	0
Seed Harvesting	0	3,000	4,000	5,000	6,000	7,000	8,000	9,000	9,500	10,000
Labor Sub-Total	12,250	9,250	10,250	6,000	7,000	8,000	9,000	10,000	10,500	11,000
Cost Total	30,536	15,661	12,121	7,991	9,931	10,271	11,451	13,491	13,291	13,871

Table 40 below provides the breakdown of costs over ten years for a Croton fence around the perimeter of a one-acre plot. It is assumed that 80 seedlings will be needed to establish and replant 72 trees, at a cost of Ksh 25 per seedling. The total planting and establishment equipment cost is Ksh 4,200. Nine person/days of hired labor is included for land clearing, plowing, and harrowing. Another five person/days is included for planting.

Table 40: Cost of Production Over Ten Years, One-Acre Fence *Croton* Plantation										
Years 1-10	1	2	3	4	5	6	7	8	9	10
Inputs (Ksh/acre)										
Seeds	2,000	0	0	0	0	0	0	0	0	0
Plant/Estab Equip	4,200	0	0	0	0	0	0	0	0	0
Fertilizer	1,696	328	328	328	328	328	328	328	328	328
Pest/Disease	2,108	308	308	308	308	308	308	308	308	308
Harvest Equip	0	1,000	100	100	1,000	100	100	1,000	100	100
Seed Processing	0	2,020	240	280	320	400	500	600	640	700
Inputs Sub-Total	10,004	3,656	976	1,016	1,956	1,136	1,236	2,236	1,376	1,436
Labor (Ksh/acre)										
Land Preparation	2,250	0	0	0	0	0	0	0	0	0
Planting	1,250	0	0	0	0	0	0	0	0	0
Fertilization	500	250	250	250	250	250	250	250	250	250
Pest Disease Mgmt	500	250	250	250	250	250	250	250	250	250
Weeding	1,500	1,500	1,500	0	0	0	0	0	0	0
Pruning	0	500	250	0	0	0	0	0	0	0
Harvesting	0	500	1,500	3,000	3,500	4,000	4,500	4,750	5,000	5,500
Labor Sub-Total	6,000	3,000	3,750	3,500	4,000	4,500	5,000	5,250	5,500	6,000
Cost Total	16,004	6,656	4,726	4,516	5,956	5,636	6,236	7,486	6,876	7,436

We assume quantities of fertilizer and pest and disease control chemicals similar to the monoculture plantation, but proportional to the number of trees in the fence. Two person/days of labor is included for fertilizer in the first year and one man/day every year thereafter. Two person/days of labor is included for pest and disease management in the first year and one every year thereafter. The budget includes three person/days two times a year for weeding the one-acre fence. Two person/days is included for year two and one man/day for year three. The first significant harvest in year three will require six person/days. Twenty-four person/days will be required by year 10.

The additional costs incurred for managing the plantation for timber as well as oilseeds are listed in Table 41. The timber harvesting will commence in year 11 and continue thereafter indefinitely with an annual harvest of five percent of the trees. The age and size of the trees will continue to increase from year 11 to 30. For purposes of simplicity we estimate a standard size tree of 20 years old. In year 31, the trees planted in year 11 will be harvested and the entire cycle will begin anew. Increased costs outlined in the Table 39 provide resources for harvesting and replanting in addition to the ongoing management and harvesting costs incurred over the first ten years. About half of the additional Ksh 3,740 required for managing the plantation and an additional Ksh 3,320 for managing the fence for sustainable timber is allocated for hiring a chainsaw and operator to cut the trees into logs to be hauled away by the timber buyers.

Table 41: Cost of Production, Years 11-30, One-Acre Monoculture & Fence *Croton* Plantations		
Inputs (Ksh/acre)	Plantation	Fence
Seedlings	200	100
Plant/Establishment Equipment	740	420
Fertilizer	935	328
Pest/Disease	416	308
Seed Harvest Equipment	200	100
Timber Harvest Equipment	1,800	1,800
Seed Processing	1,320	700
Inputs Sub-Total	5,611	3,756
Labor (Ksh/acre)		
Land Preparation	0	0
Planting	250	250
Fertilization	500	250
Pest Disease Management	500	250
Weeding	500	500
Pruning	250	250
Seed Harvesting	10,000	5,500
Labor Sub-Total	12,000	7,000
Cost Total	17,611	10,756

6.3.2 Prices, Markets and Revenue

Croton oilseeds are currently being sold to local buyers in the hard outer hull for Ksh 5 per kilogram. The only consistent market for the seeds appears to be in Central Province where two local oil processors are pressing *Croton* oil. The buyers then mechanically dehull the seeds and press and filter the oil for use locally as SVO and biodiesel. The current practice is typically that the seller makes arrangements for the buyer to pick up the seeds from the farm gate. This is why no transport costs are included in the budget, as they are borne by the oil processers/buyers and not the farmers.

Yields provided in the budget are for seeds in the hull. Seeds out of the hull currently sell for between Ksh 12-20 per kilogram. Yields for the two plantation types are provided in Tables 42 and 43. For the row plantation, we project a yield of 25 kilograms per tree by year 10 for a total of 3,600 kilograms of seeds per year. For the fence plantation, we project a yield of 20 kilograms per tree by year 10 for a total of 1,440 kilograms of seeds per year.

Table 42: Revenue Years 1-10, One-Acre Monoculture *Croton* Plantation										
Years	1	2	3	4	5	6	7	8	9	10
Number of trees per acre	144	144	144	144	144	144	144	144	144	144
Yield per tree (kg)	0	1.5	3	6	10	14	18	21	23	25
Yield per acre (kg)	0	216	432	864	1,440	2,016	2,592	3,024	3,312	3,600
Price (Ksh/kg)	5	5	5	5	5	5	5	5	5	5
Total	0	1,080	2,160	4,320	7,200	10,080	12,960	15,120	16,560	18,000

Table 43: Revenue Years 1-10, One-Acre Fence *Croton* Plantation										
Years	1	2	3	4	5	6	7	8	9	10
Number of trees per acre	72	72	72	72	72	72	72	72	72	72
Yield per tree (kg)	0	0.5	1.5	3	5	8	12	16	18	20
Yield per acre (kg)	0	36	108	216	360	576	864	1,152	1,296	1,440
Price (Ksh/kg)	5	5	5	5	5	5	5	5	5	5
Total	0	180	540	1,080	1,800	2,880	4,320	5,760	6,480	7,200

As discussed in the Section 6.1.3, *Croton* wood is used for timber, flooring, and building materials, as wells as for firewood and charcoal. The budget assumes that the wood will be sold at the farm gate as timber in the form of logs. Each tree will be felled, stripped, and cut into logs either four or five meters long. An average twenty year-old *Croton* tree is estimated to contain nineteen meters of merchantable timber. The current farm-gate price is between Ksh 700-800 per four-five meter log. Thus, we estimate an average price of Ksh 163 per log meter.

Tables 42 and 43 show the revenue from oilseeds sales for the first ten years for each plantation type. By year ten, the plantation and fence generate total revenues of Ksh 18,000 per year and Ksh 7,200 per year, respectively. Table 44 shows the additional revenue for each plantation type that begins to accrue in year 11 onwards. For both plantation types, the addition of timber increases overall revenues by more than 100%.

Table 44: Revenue Years 11-30, One-Acre Monoculture & Fence *Croton* Plantations		
Seed Revenue	Plantation	Fence
Yield (kg/acre)	3,600	1,440
Price (Ksh/kg)	5	5
Seed Revenue Sub-Total	18,000	7,200
Timber Revenue		
Yield (logs)	133	66.5
Price (Ksh/log/m)	163	163
Timber Revenue Sub-Total	21,700	10,840
Revenue Total	39,700	18,040

6.3.3 Net Margins, Break-Even Analysis and Internal Rates of Return

The annual net margins for the row plantation turn positive in year seven and grow to a maximum of Ksh 4,129 per acre by year ten (see Table 45). The fence plantation remains in the red even up to full maturity, and so never becomes profitable if only oilseeds are considered. However, when timber costs and revenues are included, the net margin starting in year 11 onward for the monoculture jumps to Ksh 22,089 per year. Including timber revenue for the fence makes the venture profitable from year 11 onward with an annual net margin of Ksh 7,284.

Table 45: Net Margins Years 1-10, One-Acre Monoculture & Fence *Croton* Plantations										
Net Margins Plantation	1	2	3	4	5	6	7	8	9	10
Ksh/acre	-30,536	-14,581	-9,961	-3,671	-2,731	-191	1,509	1,629	3,269	4,129
Net Margins Fence	1	2	3	4	5	6	7	8	9	10
Ksh/acre	-16,004	-6,476	-4,186	-3,436	-4,156	-2,756	-1,916	-1,726	-396	-236

Excluding timber revenue, the plantation model does not break even on the investment for 23 years. The fence model remains operating at a loss without timber, so never breaks even. Including timber, the plantation model breaks even within 13 years and the fence model within 16 years. Table 46 shows the internal rate of return ("IRR") for the four different plantation investments over 10, 20, and 30-year horizons. The 13.02% IRR for the Croton timber plantation seems reasonable when compared with other timber investments. For example, a calculation of IRRs conducted for 20 timber investments throughout Argentina, Brazil, Chile, Uruguay, and the southern United States averaged 12.31%, with a median of 12.65%.[clxxxvii]

Table 46: 10-Year Internal Rates of Return One-Acre Monoculture and Fence *Croton* Plantations, with Timber			
Internal Rate of Return	10 Years	20 Years	30 Years
Plantation	-22.41%	-1.40%	2.49%
Plantation with Timber	-22.41%	10.86%	13.02%
Fence	n/a	n/a	n/a
Fence with Timber	n/a	4.69%	8.00%

6.3.4 Opportunity Cost

To evaluate the attractiveness of the investment based on IRR, it is helpful to compare these returns to that of a money market account or equity investment over the same period. A money market account yielding 2% interest over 30 years yields an IRR of over 15%. An equity investment that averages 5% returns annually would yield an IRR of over 27%. Thus, when considering the relative safety of a money market account, it is hard to imagine investing in a more risky oilseed and timber plantation. However, a more realistic assessment of the value of the investment from the perspective of a small to medium-sized African farmer is to consider the opportunity cost in terms of alternative uses of the land.

6.4 Production in Kenya

6.4.1 Historic and Current Activities

There are currently various activities involving *Croton* occurring at global, regional, and national levels. We encountered *Croton* growing on and around farms in all of the six regions covered by the survey, although mainly at higher elevations around Mt. Kenya and the Central highlands, and in parts of Western and Rift Provinces. In total, 73 of the 397 farms visited contained *Croton* (see map below for locations where Croton was found). Only three farmers reported selling Croton seeds for oil. No other market currently exists for the seeds, at least amongst the farmers visited. Only two farmers were planting Croton in a monoculture plantation and both were quite small.

Map 16: Geographic Locations of *Croton* Farms Surveyed

Endelevu Energy, the lead author of this study, is also working on a new venture under the name Endelea Energy to produce flex-fuel diesel generators capable of running on SVO. *Croton* oil is one of the key feedstocks being tested. Endelea has begun testing the technology in a modified Toyota Hilux diesel truck, which is currently running on pure SVO from *Croton* oil and other locally available feedstocks. The first genset prototype was tested in Kenya in the second half of 2009. The primary market is for stationary power generation in rural areas.

The Kenya Forestry Research Institute (KEFRI) is involved in research for production, processing, and marketing of *Croton* for biofuels and reforestation. KEFRI's National Seed Centre, which was established with support from GTZ, provides certified, high quality *Croton* seeds to farmers throughout the country.[clxxxviii] Jomo Kenyatta University of Agriculture and Technology (JKUAT) and the Kenya Industrial Research Development Institute (KIRDI) are testing the use of *Croton* oil as a biodiesel feedstock.[clxxxix]

Left: A 400-liter batch biodiesel reactor near Naro Maru used by a local self help group and business to produce biodiesel from *Croton* and other oilseeds. Right: A local driver fills up with pure biodiesel (B100).

The Naro Maru Help Self Help Group and Horizon Business Ventures at the base of Mt. Kenya has been producing *Croton* oil for biodiesel and straight vegetable oil (SVO) biofuel. With the assistance of a donor, the organization obtained a small biodiesel reactor and several oil presses (see photos above). They also press edible oils from sunflower and rapeseed grown by surrounding farmers. Since diesel pump prices have dropped from the high levels witnessed in 2008, the organization has halted biodiesel production as too expensive.

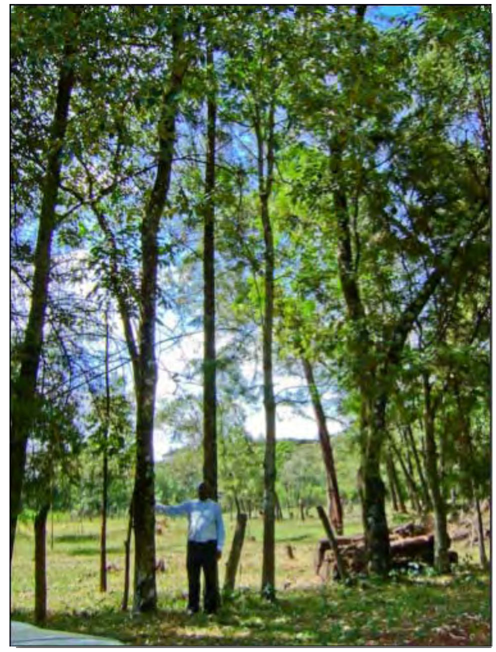
One of a dozen *Croton* trees growing on Lucheli Mwalati's farm near Kakamega, Western Province.

The Enterprise Development Centre, a community-based organization also operating in the Mt. Kenya region, is carrying out a pilot project producing biodiesel from *Croton* seeds. Seeds are manually collected and packaged from farmlands within the region by youth who sell to the processing factory, which the organization claims to be producing 400 liters per day.[cxc]

The Kakamega Education Environment Programme (KEEP) in Western Kenya is promoting forest conservation through schools, churches, and communities by encouraging nursery establishment and tree planting with *Croton*.[cxci] The African Development Bank is supporting the Kenya Forest Service initiate Green Zones Programme to conserve and rehabilitate forests in 24 districts using *Croton* species. The project supports reforestation of degraded areas by issuing free seeds to farmers.[59]

The Kenya Medical Research Institute (KEMRI), in collaboration with universities and research institutions, is initiating studies on *Croton* as a source of medicinal extracts. The studies will focus on the determination of phytochemical analysis and pharmacological properties. A group of multi-disciplinary experts are developing a *Croton* Research Network for purposes of undertaking systematic and comprehensive studies on *Croton* genera.[cxcii]

In Tanzania, the Africa Biofuel and Emission Reduction (TZ) Limited is attempting to launch a large plantation and outgrower project for *Croton* oil.[cxciii] Scientists at the University of Newcastle are designing a unique energy storage system (micro-trigeneration system), which can support a generator running on croton oil to power, heat and cool homes.[cxciv]



Joshua Webo Luvale standing next to his 25-year-old *Croton* fence near Kakamega.

6.4.2 Mapping and Overall Suitability

In addition to identifying the most attractive plantation type, we have also attempted to locate the optimal geographic locations to focus investment. To accomplish this we incorporated three categories of data into the following maps: agronomic suitability, market accessibility, and potential conflicts with existing land uses, including food, cash crops, and gazetted areas.

The *Croton* suitability map (Map 17) utilizes the agronomic conditions contained in Table 47 and described in more detail in Section 6.2.1. Suitability is divided into areas that are considered highly, moderately, and marginally suitable according to the range and optimal growing conditions listed above. 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.

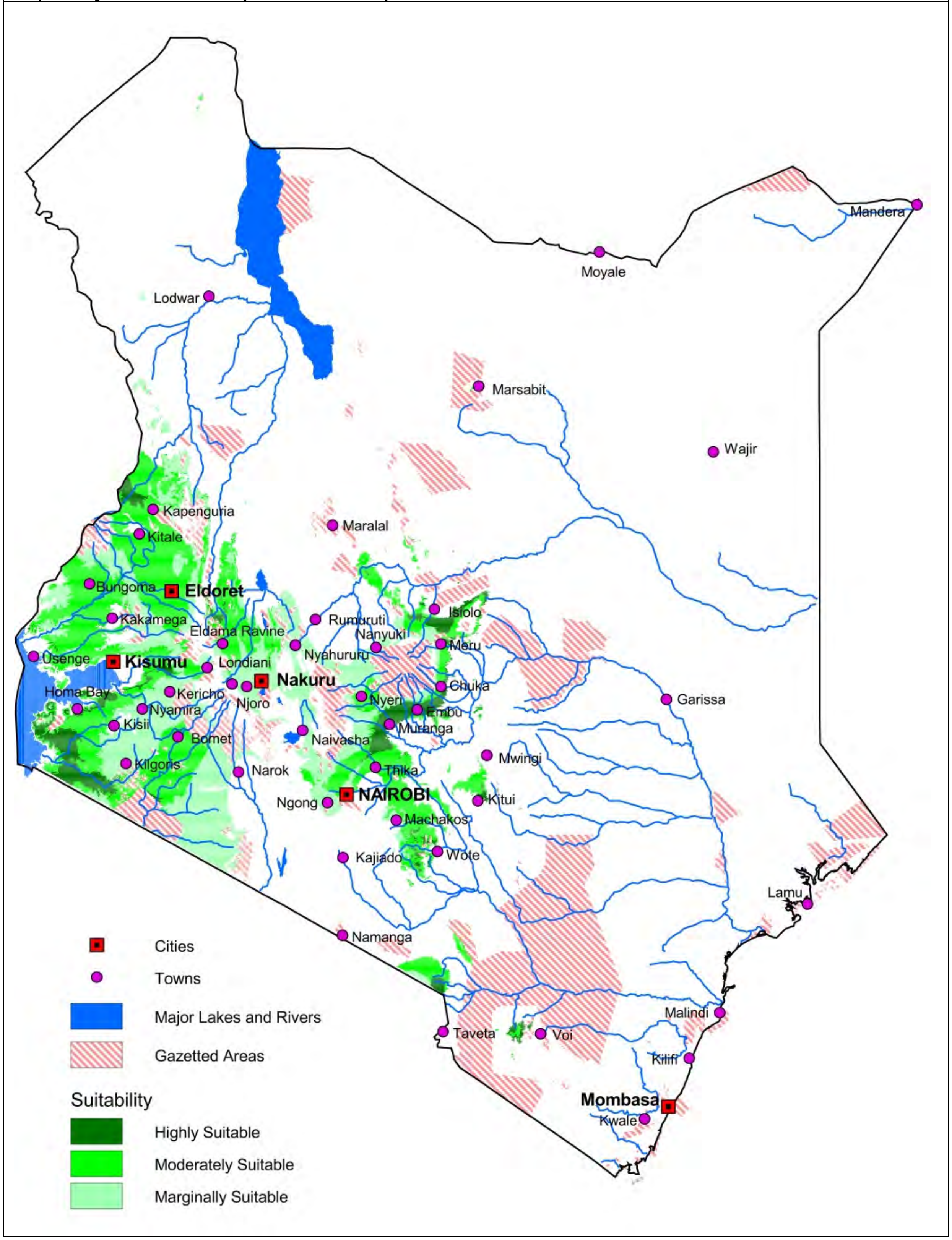
Table 47: Range and Optimal Agronomic Suitability for *Croton*

Agronomic Parameters	Range	Optimal
Annual Temperature (°C)	11-26°C	16-22°C
Annual Rainfall (mm)	800-1,900 mm	1,000-1,400 mm
Altitude (m)	1,200-2,450 m	1,200-1,600 m
Soil	Light, deep, well-drained soils.	

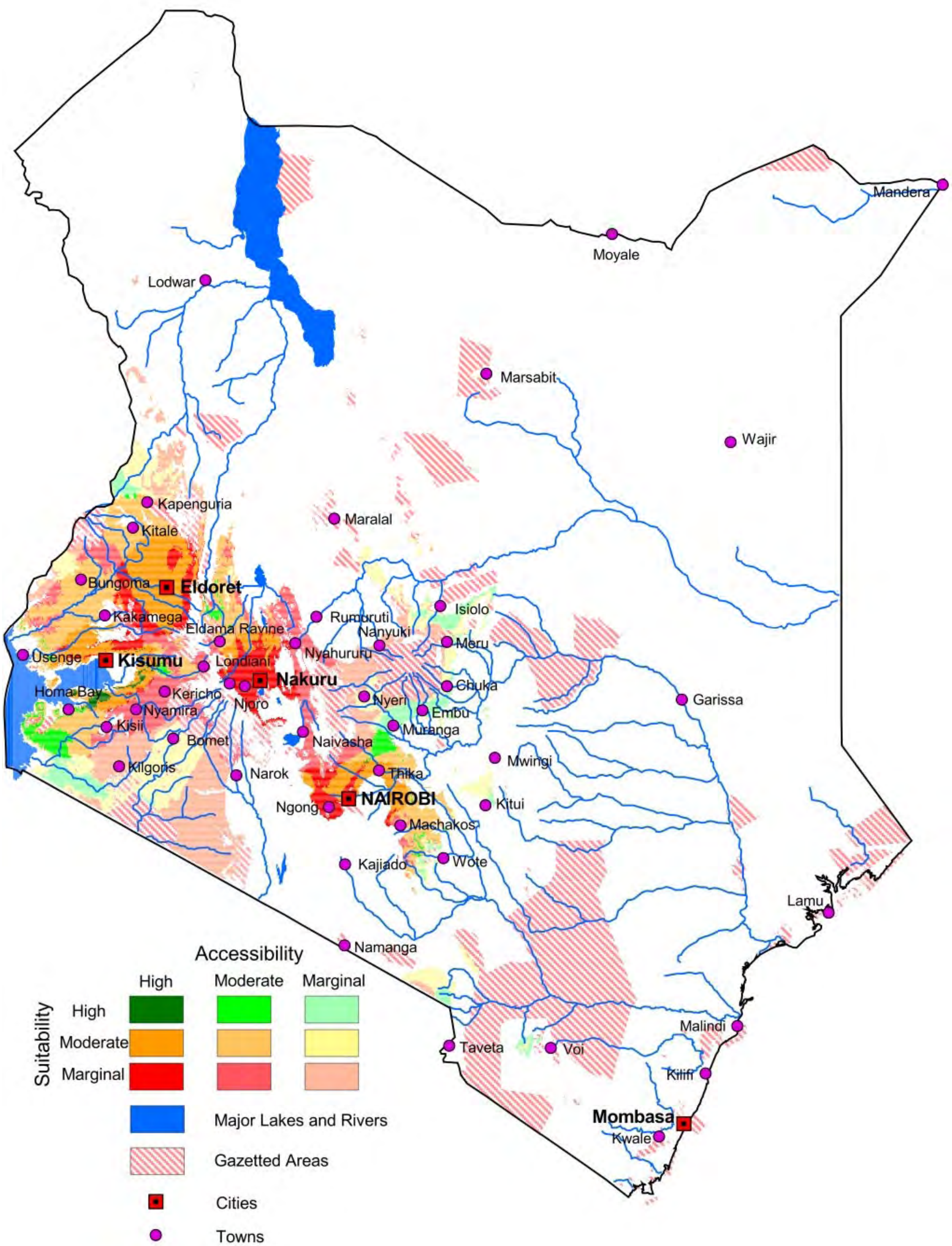
For market accessibility, we created two maps. Map 4 above shows accessibility to major cities, including Eldoret, Kisumu, Mombasa, Nairobi, and Nakuru. Map 5 above shows accessibility to major towns throughout the country. The idea was to depict accessibility for large-scale commercial investments in the first map and smaller-scale projects in the second. For both maps, accessibility is a factor of the time it generally takes to travel to the nearest city or town, according to existing road network, slope, land-use, land-cover, urban centers, and rivers and lakes.

We then combined the maps to show both suitability and accessibility together (see Maps 18 & 19). These maps use a colored grid to depict and overlay three grades of suitability – highly, moderately, and marginally – with the three grades of accessibility. A final set of maps overlay existing food and cash crop growing areas with those locations that are potentially suitable for the select oilseed crop, in this case *Croton* (see Maps 20 & 21).

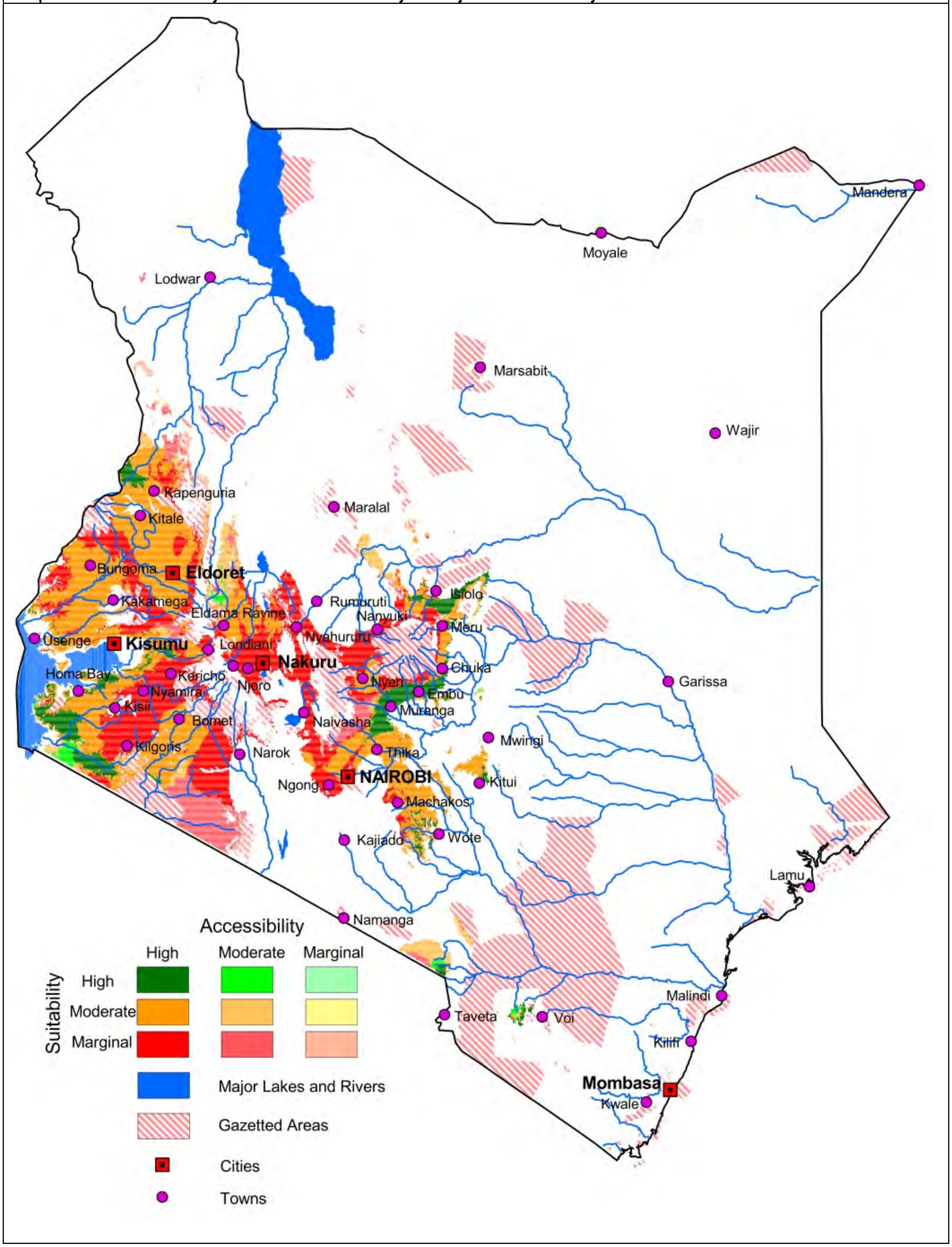
Map 17: Agronomic Suitability of *Croton* in Kenya



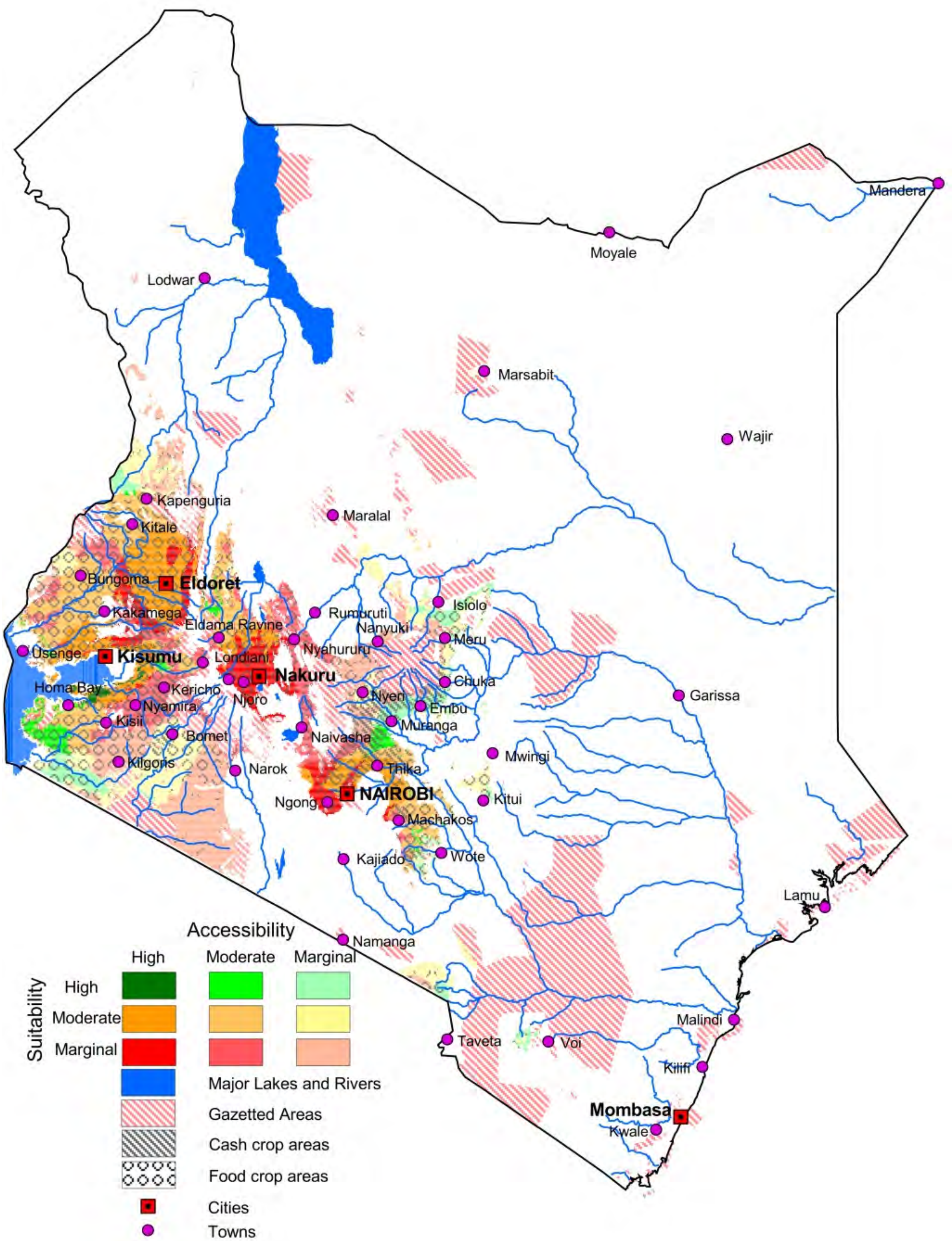
Map 18: *Croton* Suitability & Market Accessibility to Major Cities in Kenya



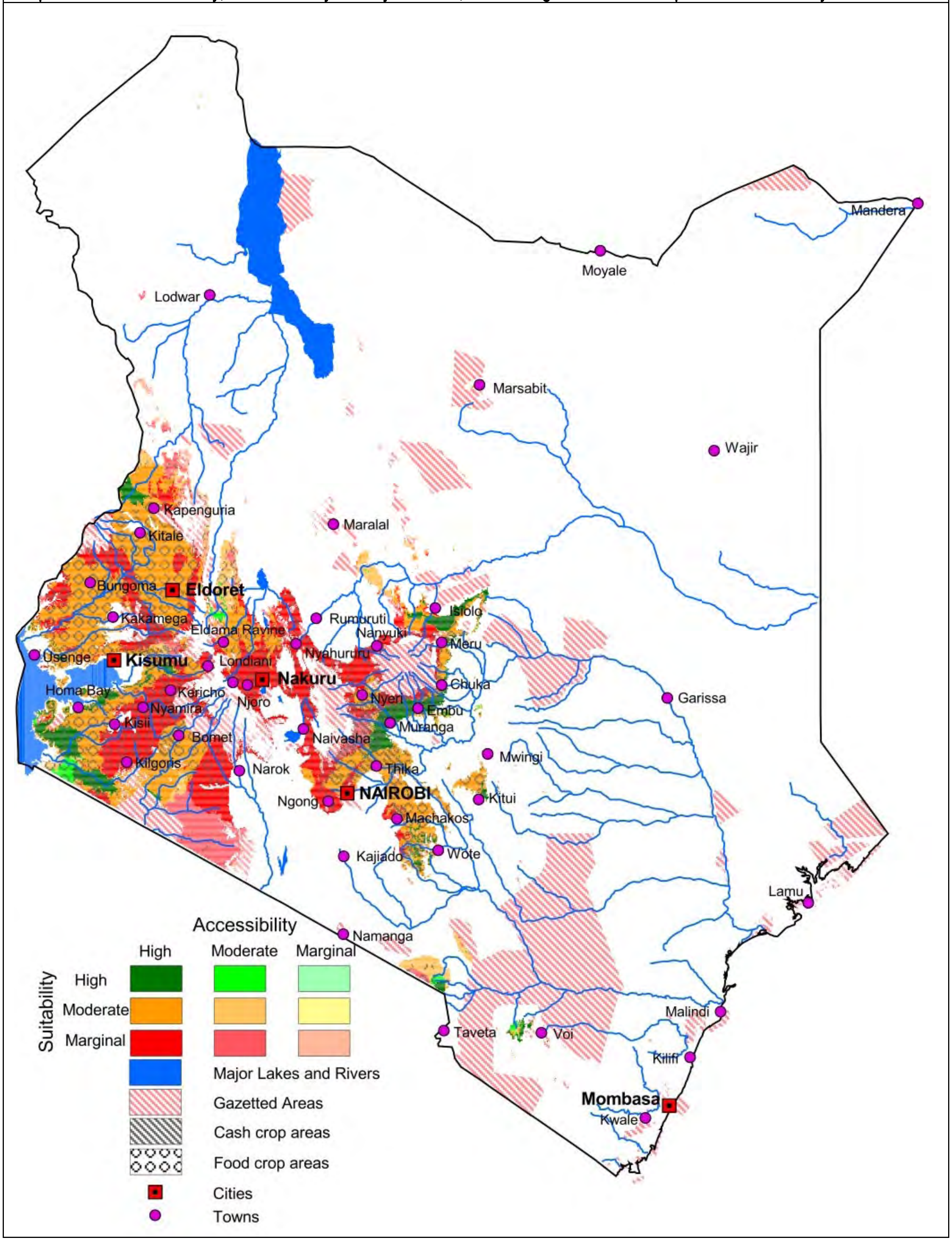
Map 19: *Croton* Suitability & Market Accessibility to Major Towns in Kenya



Map 20: *Croton* Suitability, Accessibility to Major Cities, & Existing Food/Cash Crop Land-Use in Kenya



Map 21: *Croton* Suitability, Accessibility to Major Towns, & Existing Food/Cash Crop Land-Use in Kenya



6.5 Outlook, Potential and Obstacles

Croton seedlings propagating naturally in the wild.

There are many hundreds of thousands, if not millions, of *Croton* trees growing wild, in agroforestry systems and around homesteads throughout Kenya, but particularly near Mt. Kenya, Western Province, around the Mau Forest complex, and in and around Nairobi. Some of the critical obstacles for the development of *Croton* for biodiesel production include a lack of knowledge on the best silvicultural practices, such as spacing, pruning, and the correlation between fertilization of trees and yields. Seed harvesting and post-harvest handling techniques also have not been established and standardized. There remains a lack of seed processing methods for shelling seeds and oil extraction at the local level, where access to oil could have an immediate and significant affect on development. Capacity is limited at all levels along the *Croton* value chain.

Nonetheless the potential for production, processing and utilization of *Croton* seeds for biofuels is enormous. This is because *Croton* is an indigenous, multi-purpose, agroforestry species with wide climatic adaptability. It has been domesticated over many years without many known pests and diseases. Although systematic studies have yet to be done on yields per tree, especially for monoculture planting, it is suspected that yields may exceed 25 kilograms per tree. The oil content of the seeds is also appreciably high at 30%. Additionally, *Croton* seedcake may be a highly suitable animal feed, especially for poultry. The potential for processing seeds at local level into straight vegetable oil is attractive for use in lighting, cooking, and electricity generation using adjusted equipment.

There is a need to design and establish agronomic research trials for determining best practices and identifying superior, seed-producing trees. There is also an urgent need to undertake countrywide census of different age classes of *Croton* trees and to determine accurate seed yield estimates. A final recommendation, mainly aimed at the private sector, is to design and mainstream an integrated model of production, processing, utilization, and marketing for *Croton*-based biofuel systems.

7. Oil Suitability Analysis

A key threshold for considering the use of any vegetable oil as a biofuel is the chemical characteristics of the oil. Viscosity, iodine number, carbon residue, and other parameters determine the oil's suitability for conversion to biodiesel or for use as an SVO fuel. As part of the study, we conducted laboratory tests on samples of straight *Castor*, *Croton*, and *Jatropha* oil, as well as biodiesel produced from the latter two. A sample of *Castor* biodiesel was unavailable, so we have included characteristics of *Castor* biodiesel from tests conducted and reported on elsewhere. The results are presented below, as well as an explanation of the relevance of each test.

Samples of *Croton, Jatropha,* and *Castor* SVO (from left to right).

7.1 Straight Vegetable Oil Tests

Germany has established a biofuel standard for the use of straight *Rapeseed* oil in diesel engines.[cxcv] As the only official SVO biofuel standard in the world, we have used its parameters as a measure to test the suitability of SVO produced from *Castor*, *Croton*, and *Jatropha* (see Table 48). However, the standard is based on the unique characteristics of *Rapeseed*, which vary from other oils, so in some cases may not provide a fair comparison. In other words, it may be possible to safely operate a diesel engine outside of the range of the *Rapeseed* standard for certain parameters, although this must be tested and verified scientifically before conclusions can be drawn. For example, Croton oil did not meet the German SVO standard for sulfur content, but did fall within the permissible standard for diesel in Kenya. All of the parameters that fall outside of the *Rapeseed* standard are shown in red and are discussed following the table.

Table 48: Comparison Between *Castor, Croton* & *Jatropha* SVO with German SVO & Kenya Diesel Standards

Property	German SVO	Kenya Diesel[cxcvi]	*Castor* SVO	*Croton* SVO	*Jatropha* SVO
Density (kg/m^3)	900-930	820-870 (@ 20°C)	959.3	922	916.2
Flash Point (°C)	220°C min	60°C min	263	227	213
Viscosity (mm^2/S @ 40°C)	38 max	1.6-5.5	243.1	28.8	33.3
Carbon Residue (% mass)	0.4 max	0.15 max	0.03	0.69	0.11
Iodine Number (g/100g)	100-120	-	82.56	142.88	108.57
Sulfur Content (ppm)	20 max	500 max	17	400	91
Acid Number (mg KOH/g)	2 max	0.5 max	0.61	2.48	2.10
Phosphorous (ppm)	15 max	-	900	300	100
Calorific Value (kJ/kg)	35,000 min	-	36,800	38,510	38,490
Oxidation Stability (hours)	5 min	-	86	78	62
Ash (% mass)	0.01 max	0.01 max	<0.01	<0.01	0.02
Water (% mass)	0.075	0.05 max	0.01	<0.05	<0.05
Cloud Point	n/a	12°C max	n/a	n/a	n/a
Cetane Number	n/a	48 min	n/a	n/a	n/a
Contamination (mg/kg)	25 max	-	n/a	n/a	n/a

7.2 Biodiesel Tests

We also conducted laboratory analyses on biodiesel produced from *Castor*, *Croton*, and *Jatropha*. Table 49 compares the results of these tests with the official biodiesel standards in the United States, European Union, and Brazil, as well as the draft biodiesel standard that has been proposed by the Kenya Bureau of Standards.

Table 49: Comparison Between *Castor*, *Croton* & *Jatropha* Biodiesel with US, EU, Brazil & Kenya Draft Standards

Property	USA B100[cxcvii]	EU B100[cxcviii]	Brazil B100[cxcix]	Kenya Draft B100[cc]	Kenya Diesel[cci]	*Castor* B100[ccii]	*Croton* B100	*Jatropha* B100
Density (kg/m^3)	–	860-900	Report	875-900	820-870	926.8	892.7	889.2
Flash Point (°C min)	93°C	101°C	100°C	66°C	60°C	190.7	185	153
Viscosity (mm^2/S @ 40°C)	1.9-6.0	3.5-5.0	Report	1.5-4.1	1.6-5.5	13.5	6.094	6.170
Carbon Residue (% mass)	0.05 max	0.3 max	0.1 max	0.15 max	0.15 max	0.037	0.02	0.06
Iodine Number (g/100 g)	–	120 max	–	–	–	85.2	135.25	122.10
Sulfur Content (ppm)	15/500 max	10 max	500 max	TBD	500 max	40	10	17
Acid Number (mg KOH/g)	0.5 max	0.5 max	0.8 max	0.3 max	0.5 max	0.42	0.4	0.42
Phosphorous (mg/kg)	10 max	4 max	Report	0.001 max	–	n/a	n/a	n/a
Oxidation Stability (hours)	3 min	6 min	6 min	–	–	n/a	63	60
Sulfated Ash (% mass)	0.02 max	0.02 max	0.02 max	0.01 max	0.01 max	n/a	0.01	0.01
Water & Sediment (% vol)	0.05 max	–	0.05 max	0.05 max	0.05 max	n/a	n/a	n/a
Water Content (ppm)	500 max	500 max	–	–	50 max	n/a	n/a	n/a
Cloud Point (°C)	Report	–	–	Report	12°C max	-23	-5.0	0
Cetane Number	47 min	51 min	Report	48 min	48 min	n/a	n/a	n/a
Contamination (mg/kg)	–	24 max	Report	–	–	n/a	n/a	n/a
Copper Strip Corrosion	Class 3	Class 1	Class 1	Class 3	Class 1	1B	1A	1A
Free Glycerol (% mass)	0.02 max	0.02 max	0.02 max	–	–	0.015	n/a	n/a
Total Glycerol (% mass)	0.24 max	0.25 max	0.38 max	–	–	0.018	n/a	n/a
Ester Content (% mass)	–	96.5 min	Report	–	–	n/a	n/a	n/a
Distillation Temp. (°C)	360°C max	–	360°C max	345°C max	90-400°C	n/a	n/a	n/a
Alcohol Content (% mass)	0.20	0.20 max	0.50 max	–	–	n/a	n/a	n/a
Monoglyceride (% mass)	–	0.8 max	–	–	–	n/a	n/a	n/a
Diglyceride (% mass)	–	0.2 max	–	–	–	n/a	n/a	n/a
Triglyceride (% mass)	–	0.2 max	–	–	–	n/a	n/a	n/a
Group I Metals (Na, K) (mg/kg)	5 max	5 max	–	–	–	n/a	n/a	n/a
Group II Metals (Ca, Mg) (mg/kg)	5 max	5 max	–	–	–	n/a	n/a	n/a

7.3 Discussion of Testing Parameters

The following section discusses the individual testing parameters for which any of the three SVOs or biodiesels were unaligned. The discussion begins by explaining the relevance and meaning of the parameter, then explains the significance of the failure to comply and what measures can be taken to change the characteristic of the SVO or biodiesel for compliance.

7.3.1 Density

The density of vegetable oil and biodiesel is generally about 10-15% higher than that of mineral diesel.[cciii] Fatty acid composition and purity affect density, which increase as the length of the fatty acid chain gets smaller and the number of double bonds increase. Low-density additives like methanol decrease also decrease density.[cciv] Both the SVO Standard and the European Biodiesel Standard (EN) limit density at both the upper and lower level. However, both the US and the Brazilian standards simply require density to be reported, but do not impose limits. Some experts have questioned the value of the density specification, in particular in the US and Brazil, feeling that the other test parameters sufficiently determine the fuel's suitability, while certain feedstocks like *Coconut* and *Castor* oil would be excluded by the European density limits.[ccv]

The test results indicate that *Croton* and *Jatropha* SVO and biodiesel satisfy the EN standard, but *Castor* exceeds both. Interestingly, Kenya's proposed biodiesel standard would impose an even stricter density limit than even the EN standard. This decision should be considered in light of the promising potential of Castor oil feedstock to be used in Kenya, as well as the fact that neither the US or Brazil have chosen to limit density, the latter in large part due to the need to include feedstocks such as *Castor*.

7.3.2 Flash Point

Flash point is a measure of the fuel's flammability. It is used primarily to determine the safety precautions necessary for transport and storage. Vegetable oil and biodiesel generally have flash points much higher than that of mineral diesel, and thus provide an advantage in terms of safety. Flash point will decrease significantly by the increased presence of residual alcohol from the biodiesel conversion process. Accordingly, flash point can be used to determine the purity of biodiesel and the completeness of the conversion process.[ccvi]

The flash point limit under the SVO standard is 220°C, which is 100°C higher than the equivalent limit under the EN biodiesel standard. Of the three feedstocks, *Jatropha* SVO fell slightly below the SVO standard, but still exceeded the biodiesel standards lower limits by about 100°C, depending on which standard is used. Biodiesel produced from all three feedstocks remain safely above the limit for flash point under all three standards and the Kenya draft, which, at 66°C, is proposed well below those of other parts of the world. The proposed flash point for Kenya is also well below the 100°C minimum used by the National Fire Protection Association to determine whether a substance is considered a fire hazard.[ccvii] Kenya may want to reconsider establishing such a low flash point, as both fuel quality and safety might be compromised.

7.3.3 Kinematic Viscosity

Kinematic viscosity is the speed over which a liquid passes a certain distance, which determines the fluidity of the substance. Viscosity of biofuel is important due to its affect on volume flow and injection spray characteristics. Vegetable oils and biodiesels become less viscous at higher temperatures, meaning that high viscosity fuels may cause problems in cold weather climates, including the integrity of the injection pump drive system.[ccviii] Viscosity may also affect fuel atomization, which can lead to larger droplets being injected into the compression chamber and less efficient fuel consumption.[ccix]

One of *Castor* oil's great strengths for many industrial applications – its extremely high viscosity – may be one of its greatest weaknesses as a feedstock for biofuels. As the SVO tests indicate, *Castor* oil is nearly 10 times as viscous as *Croton* or *Jatropha* when tested at 40°C, which is well above the upper limit for viscosity under the SVO standard.

Heat and transesterification are two ways of reducing the viscosity of vegetable oil. For example, raising the temperature of Castor oil from 40°C to 60°C reduces its viscosity by at least 50%.[ccx] Converting Castor to biodiesel by way of transesterification reduces viscosity from over 240 centistokes to 13.5. However, that is still more than twice the upper limit under any of the biodiesel standards. Another way of reducing viscosity to acceptable levels is to blend biodiesel with mineral diesel. Testing shows that B10 and B20 blends will reduce viscosity to 4.54 and 4.97 centistokes, respectively.[ccxi]

Both *Croton* and *Jatropha* SVO satisfy the SVO standard, but are slightly above the upper limit for biodiesel under the US standard. The proposed Kenya standard sets a stricter upper limit for viscosity than even the EU standard, which seems unduly restrictive and should be revised, especially in light of the results of our testing on locally available feedstocks. In the least, the Kenya biodiesel standard should not be more limited than that currently allowed in Kenya for diesel. It is also recommended that more testing be done regarding *Castor* biodiesel and *Castor* SVO blends to achieve the desired level of viscosity to ensure engine integrity.

7.3.4 Carbon Residue

Carbon residue is defined as "the amount of carbonaceous matter left after evaporation and pyrolysis of a fuel sample under specific conditions."[ccxii] A higher carbon residue may lead to unwanted deposits in the compression chamber, injector tips, valves, and piston rings.[ccxiii] Carbon residues may also lead to coking and soot formation in the exhaust. The *Croton* SVO sample tested contained a carbon residue level above the SVO standard. This may be reduced to below the upper limit in the SVO standard through the use of fuel additives, or by converting the SVO into biodiesel. All other SVO and biodiesel standards were lower than the associated standards.

7.3.5 Iodine Number

Iodine number, or value, shows the amount of unsaturation of the SVO or biodiesel, based on the number of double bonds in the molecular structure. It is measured by the number of grams of iodine that react with 100 grams of SVO or biodiesel.[ccxiv] The higher the iodine number, the greater number of unsaturated fatty acids present in the fuel. The more unsaturated the oil (the higher the iodine number), the more likely it is to polymerize in the heat of the engine. However, tests have shown that polymerization in engines occurs only with oils that contain three or more double bonds, which is limited to a small number of vegetable oils.[ccxv] Importantly, iodine number cannot determine the number or position of double bonds, but merely the amount of unsaturation of the oil. As a result, many experts agree that the iodine number may not be the most appropriate or accurate test for determining whether an oil will polymerize and lead to engine problems.[ccxvi] Instead, it has been suggested that limits on linolenic acid, polyunsaturates and oxidation stability are sufficient to determine the oil's suitability for fuel.[ccxvii]

Both *Croton* SVO and biodiesel contain iodine numbers above the upper limit permitted by the EU SVO standard and the EU biodiesel standard. None of the other standards contain a limit on iodine number. It is recommended that research into the chemical structure of *Croton* oil be conducted to determine the number of double bonds, as well as the level of linolenic acid and polyunsaturates. It is also recommended that engine wear tests be conducted to determine whether polymerization occurs with the long-term use of *Croton* SVO or biodiesel.

7.3.6 Sulfur Content

High sulfur fuels create more sulfur dioxide and particulate matter, and thus contribute to adverse human health impacts. In most of the world, the allowable sulfur level for biodiesel is consistent with the sulfur limits placed on mineral diesel. In the US standard, two levels are given: 15 ppm for on-road use and 500 ppm for off-road. In the EU, the standard is 10 ppm for biodiesel and 20 ppm for SVO, reflecting the strict controls on sulfur pollution for diesel. The sulfur limit in the Brazilian standard is 500 ppm. No sulfur level has been included yet in the draft Kenya standard, although the Kenya diesel sulfur limit is currently set at 500 ppm. Accordingly, even the highest sulfur level tested, which was 400 ppm for *Croton* SVO, would comply with current Kenyan standards.

Many proponents of biofuels repeat the false claim that biodiesel and SVO are sulfur-free. While it is true that most vegetable oils have very low sulfur content, it is untrue that they are completely free of it, as our laboratory test results show. Curiously, the test results anomalously show that *Croton* SVO contains 400 ppm of sulfur and *Croton* biodiesel contains 10 ppm, whereas *Jatropha* SVO tested 91 ppm and Jatropha biodiesel 17 ppm. It is not surprising that the sulfur content dropped as the SVO was converted to biodiesel. What is surprising, though, is that the amount of sulfur reduced in *Croton* by 40 times, whereas for *Jatropha* it only reduced by a little for 5 times. Unacceptably high sulfur levels can be reduced with the use of magnesium silicate in the purification process.[ccxviii]

7.3.7 Acid Number

The acid number is the measure of free fatty acids in the fuel, which is the result of both the type of feedstock and the conversion process being used. An incomplete transesterification process may result in a higher acid number. Post-reaction neutralizers can be used to lower the acid number, as well. High free fatty acid content may cause engine corrosion and thermal instability.[ccxix]

The test results show that both samples of *Croton* and *Jatropha* SVO exceeded the German SVO standard. This could likely be controlled by the addition of certain neutralizers to the refining process. For biodiesel, all three samples would comply with the US, EU, and Brazilian B100, and Kenya Diesel standards. Curiously, the acid number proposed in the Kenya B100 standard is more restrictive than its counterparts in other parts of the world, as well as the current Kenya diesel standard. This should be reevaluated and harmonized with existing standards.

7.3.8 Phosphorous Content

Phosphorous content results from the type of feedstock and the production process. High levels of phosphorous can act as an abrasive agent and can adversely impact exhaust catalytic systems.[ccxx] Phosphorous can be removed by degumming the oil, which is a common process that uses water or acid to reduce the presence of phospholipids in the oil. None of the SVO samples tested had been degummed prior to testing, so, not surprisingly, phosphorous levels are quite high.

8. Conclusions and Recommendations

Jatropha remains an undomesticated plant that requires significant agronomic advances to live up to the hype that has been generated over the past several years throughout the world. Some researchers claim to be making progress towards higher yielding, homogenous, drought-resistant varieties, although the results of such research have not yet become commercially available, especially for smallholder farmers in places like Kenya. It is unclear how long it might take for such efforts to be realized, but until such time, and based on the findings from our fieldwork and subsequent analysis, *we recommend that Jatropha should not be promoted among smallholder farmers as a monoculture or intercropped plantation crop.*

Experiences in Kenya among hundreds of farmers growing Jatropha show extremely low yields and generally uneconomical costs of production. We recommend that all stakeholders reevaluae their activities promoting Jatropha among smallholder farmers in light of this study. We also urge all public and private sector actors to pose promoting the crop among smallholder farmers for any plantation other than as a fence.

The only type of *Jatropha* plantation that we can recommend for smallholders at this time is the fence. Not only does this survey show that a *Jatropha* fence can be a sound investment for smallholder farmers, but it is also a widespread, existing use of *Jatropha* that farmers are aware of and would likely be willing to adopt quite easily without reducing food production. The fence also has the additional benefit of protecting valuable plantation crops from trespassing wildlife and people.

Jatropha could become a complementary component of a diverse livelihood strategy that contributes to overall increased agricultural productivity. However, the lack of scientific knowledge on agronomy, such as high-yielding seeds, best management practices, and optimum soil fertility, inhibits the delivery of effective farmer extension services. Another obstacle is that most growers are geographically dispersed and have yet to produce large enough quantities of seeds to achieve the economies of scale necessary for efficient biofuels processing. A final problem involves whether smallholder farmers with little access to capital can afford to wait the years it will take to recoup their investment and start making a profit.

Difficult problems like energy security and global warming necessitate complex answers. When it comes to biofuels development in places like Kenya, it is essential to consider a range of potential feedstocks instead of just one. There is no single "miracle crop" that will enable sustainable biofuels development to succeed. However, some very promising opportunities exist in the short term with Castor, Croton, and other oilseeds. If developed comprehensively, these crops could contribute to the significant expansion of a mature industry within a few years.

Castor has great potential, but is lacking commercial investment in Kenya. Superior, high yielding seed varieties and extensive agronomic knowledge exist globally, but must be developed at the local level. Field trials to assess cost of production and yields under different management regimes are also important in order to identify the most profitable business models. Local processers must also import the machinery required to process high-quality Castor oil.

There are many hundreds of thousands, if not millions, of Croton trees growing wildly and in agroforestry systems throughout Kenya. Some of the critical obstacles for the development of

Croton for biodiesel production include a lack of knowledge on the best silvicultural practices, such as spacing, pruning, and the correlation between fertilization of trees and yields. Seed harvesting and post-harvest handling techniques also have not been established and standardized. Nonetheless the potential for production, processing and utilization of Croton seeds for biofuels is substantial.

There is a need to design and establish agronomic research trials for determining best practices and identifying superior, seed-producing trees. There is also an urgent need to undertake countrywide census of different age classes of *Croton* trees and to determine accurate seed yield estimates. A final recommendation, mainly aimed at the private sector, is to design and mainstream an integrated model of production, processing, utilization, and marketing for *Croton*-based biofuel systems.

It is important to stress that all actors promoting biofuels should not pick biofuel crop winners and losers without sufficient hard data, but rather should focus on supporting research and development to determine which crops prove to be the most attractive investments for farmers and other investors. Research institutions and –activities should prioritize balanced, unbiased, and fact-based data collection and dissemination. We also recommend that resources be devoted towards research trials for real farmers in diverse agro-ecological conditions with a variety of oilseed feedstocks.

Appendix 1: Farmer Questionnaire

TIME & LOCATION (Latitude, Longitude & Altitude from GPS)
1. Date: _____ day _____ month 2. Time: ______:______ am pm
3. Survey Number: _______________ (in sequence, starting with 001)
4. Region (circle one): Coast (CO) Shimba Hills (SH) Eastern (EA) Central (CE) South/Nyanza (SR) North Rift (NR) Western (WE)
5. Province: _____________________ 6. District: ______________________ 7. Division: ______________________
8. Longitude: ____________________ 9. Latitude: ______________________ 10. Altitude: ______________________
BACKGROUND & SOCIO-ECONOMIC STATUS
Interviewer
11. Interviewer: ___________________________ 12. Age: ______ 13. Gender: M F
14. Occupation: ____
15. Education (circle): None Primary Secondary Polytech College/Univ. Graduate
Interviewee/Farmer
16. Individual Interviewed: ____
17. Email: ______________________________________ 18. Phone: ____
19. Address: ____
20. Nearest town: ________________________________ 21. Distance to nearest town: _______kms
22. Distance from all weather road? __________kms
23. Do you have a regular water source on the farm? None Borehole River/Stream Other: ______________
24. Are you involved in a farmers' group? Yes No
25. How many people live on your shamba or homestead? ________
26. How many men over 15? _______ 27. Women over 15? _______
28. Boys under 15? _______ 29. Girls under 15? _______
30. Do you have the following items (circle any that apply)? Radio Mobile Phone Bicycle Car Electricity/Generator Tractor Plough Water Tank/Well
31. Do you have cattle? Yes No 32. How many cattle? ______
33. Do you have sheep? Yes No 34. How many sheep? ______
35. Do you have goats? Yes No 36. How many goats? ______
AGRONOMY, LAND USE, & OPPORTUNITY COST (Rainfall & Temperature from Database)
37. Avg. Annual Rainfall: ________mm -________mm 38. Annual Temp. Range: _______C - _______C
39. Soil Type (circle): Black Cotton Chalky Clay Loamy Peaty Sandy Silty
40. Current Land Use (circle): Agroforestry Farming Forest Grazing Scrub/Wasteland
41. How many acres is your farm? __________ 42. Do You Own or Rent the Land? Own Rent
43. What Type of Ownership/Title? Freehold Communal Trust Government
44. How much does land cost per acre in this area? _____________Ksh/acre
45. Of the land you rent or own, how many acres are currently under agricultural production? _______
46. Do you grow any non-biofuels crops for cash? Yes No (just for my own subsistence)

Please answer the following questions for the top 3 crops you grew last year other than for biofuels:			
	Crop 1	Crop 2	Crop 3
Name of Crop	47.	52.	57.
Acres Planted	48.	53.	58.
Harvest (kg/acre/yr)	49.	54.	59.
Cost of Prod. (Ksh/acre)	50.	55.	60.
Price (Ksh/kg)	51.	56.	61.

BIOFUELS ACTIVITIES

62. What biofuels crops are you growing? (circle all that apply) Castor Croton Jatropha

63. How many acres of Castor are you growing? ____ 64. How many Castor plants do you have? ____

65. How many acres of Croton are you growing? ____ 66. How many Croton trees do you have? ____

67. How many acres of Jatropha are you growing? ____ 68. How many Jatropha trees do you have? ___

(IMPORTANT NOTE - FILL OUT ONE "MANAGEMENT & ECONOMICS" FORM FOR EACH BIOFUELS CROP GROWING ON THE FARM & ONE "MEASUREMENT & YIELD" FORM FOR EACH BIOFUELS CROP GROWING ON THE FARM. IF A CROP HAS MORE THAN ONE AGE CLASS, MEANING THE FARMER HAS PLANTED THAT CROP ON MORE THAN ONE OCCASION, THEN SELECT THE PLOT/AGE CLASS WHICH IS THE MOST PRODUCTIVE OR HEALTHY LOOKING)

MANAGEMENT & ECONOMICS (If planted at different times, select the most productive plot or age class)

69. Survey Number (from question 3 on the first page): ______ 70. Type of Crop: Castor Croton Jatropha

71. When was this plot planted? _______ mos. _______ yr 72. How many acres are planted in this plot? ________

73. How many trees do you have in this plot? ________ 74. What is the spacing being used? _____m x _____m

75. What type of plantation is it? monoculture intercropped fence other: ___________________________________

76. If intercropped, what type of crop(s) is/are planted with the biofuel crop? maize beans cassava peas other: ______________

77. What propagation method did you use? seeds seedlings cuttings other: ____

78. What geographic region do the seeds come from? ____

79. Do You Hire Labour (circle one)? Yes No 80. What is the daily wage for a farm laborer locally? __________Ksh/day

81. Is labour available (circle)? Always Most of the Time Some of the Time Rarely

82. What size pits did you use for planting, if any? ______ cm x ________cm no pits

83. What type(s) of pests or diseases have affected your biofuel crop over this past year (circle all that apply)?
red spider mite golden beatle fungus powdery mildew leaf spotting other: ___________________________

Category	Description of Application	Equipment Used	Economic Data on Input Costs		
			Equip./Materials Ksh	Family Labour man/days/year	Hired Labour man/days/year
Seed/Seedlings: How many kgs of seed did you use to plant in the 1st year?		Equipment Used	Price@kg		
84.		85.	86.		
Land Preparation: How many days spent preparing land in the 1st year?		Equipment used?	Cost (Ksh)		
87.		88.	89.	90.	91.
Planting: How many days spent planting in the 1st year?		Equipment used?	Cost (Ksh)		
92.		93.	94.	95.	96.
Replanting: How many days spent replanting this past year?					
97.				98.	99.
Irrigation: How many times (treatments) per month do you irrigate?		Equipment used?	Cost (Ksh)		
100.		101.	102.	103.	104.
Irrigation: How many liters per tree per treatment do you use?		Cost of Water per Liter (Ksh/L)			
105.		106.			
Fertilizer: How many times per year did you apply fertilizer this past year?		What type(s) did you use?	Cost (Ksh/kg)		
107.		108.	109.	110.	111.
Fertilizer: How many grams per tree or kgs per acre do you use per treatment?					
112. grams/tree kgs/acre					
Pest/Disease: How many times per year did you apply pest/disease control?		What type(s) of control?	Cost (Ksh/kg)		
113.		114.	115.	116.	117.
Pest/Disease: How many grams per tree did you use per treatment?					

118.				
Weeding: How many times did you weed this past year?	Equipment used?	Cost (Ksh)		
119.	120.	121.	122.	123.
Pruning: How many times did you pruning this past year?	Equipment used?	Cost (Ksh)		
124..	125.	126.	127.	128.
Harvesting: How many times did you harvest this past year?	How many kgs did you harvest this past year?			
129.	130.			
Sales/Revenue: To whom did you sell this year (circle all that apply)?	How many kgs did you sell this past year?		What price per kg did you sell?	
131. Farmers Merchants/Traders Oil Processor Export	132.		133. Ksh	

MEASUREMENTS & YIELD (If planted at different times, select the most productive plot/age class)						
134. Survey Number (from question 3 on the first page): ______				135. Type of Crop: Castor Croton Jatropha		
136. When was this plot planted? _______ mos. _______ yr						
137. Measure the height in meters of 6 trees randomly selected:						
138. Count the number of major branches (greater than 10 cm in length) of 6 trees:						
139. Count the the number of fruits per major branch of 6 trees:						
140. What months did these Jatropha trees flower over the past year?						
141. What months did these Jatropha trees fruit over the past year?						
142. How many kilograms of dried seeds did you obtain on average per tree?						
143. How many kilograms of dried seeds did you obtain on average per acre?						

Appendix 2: Focus Group Questionnaire

TIME & LOCATION

1. Date: _____ day _____ month 2. Time: ______:______ am pm

3. Survey Number: ________________ (in sequence, starting with 001)

4. Region (circle one): Coast (CO) Shimba Hills (SH) Eastern (EA) Central (CE) South/Nyanza (SR) North Rift (NR) Western (WE)

5. Province: ______________________ 6. District: ____________________ 7. Division: ____________________

BACKGROUND INFORMATION

8. Interviewee 1: __________________________ 9. Organization: __________________________

10. Title: __________________________ 11. Phone: __________________________ 12. Email: __________________________

12. Interviewee 2: __________________________ 13. Organization: __________________________

14. Title: __________________________ 15. Phone: __________________________ 16. Email: __________________________

17. Interviewee 3: __________________________ 18. Organization: __________________________

19. Title: __________________________ 20. Phone: __________________________ 21. Email: __________________________

22. Interviewee 4: __________________________ 23. Organization: __________________________

24. Title: __________________________ 25. Phone: __________________________ 26. Email: __________________________

27. Interviewee 5: __________________________ 28. Organization: __________________________

29. Title: __________________________ 30. Phone: __________________________ 31. Email: __________________________

32. Interviewee 6: __________________________ 33. Organization: __________________________

34. Title: __________________________ 35. Phone: __________________________ 36. Email: __________________________

OPPORTUNITY COST

Please answer the following questions for the top 3 crops currently grown in your district:

	Crop 1	Crop 2	Crop 3
Name of Crop	37.	42.	47.
Acres Planted	38.	43.	48.
Harvest (kg/acre/yr)	39.	44.	49.
Cost of Prod. (Ksh/acre)	40.	45.	50.
Price (Ksh/kg)	41.	46.	51.

CASTOR DATA

52. Is Castor growing in your district? Yes No

53. Is Castor being planted or growing wild or both? Plantations Wild Both

54. Are there active Castor plantations that have been planted within the past 5 years? Yes No

55. Is anyone actively harvesting Castor that is growing in the wild? Yes No

56. What percentage of farms in your district do you estimate are growing Castor?

<1% 1-5% 5-10% 10-20% 20-50% 50-75% 75-100%

57. What is the total number of farms in your district? ______________________________

58. What is the potential for Castor in your district? Very Good Good Neutral Bad

59. What are the main obstacles to its development?

Quality Planting Material Market Agronomic Knowledge Other: ______________________________

60. What areas in your district have the most Castor activity? ______________________________

Who is growing Castor (try to get small, medium, and large scale producers to visit)?

Farmer Name 1: ______________________ Phone: ______________ Location: ____________________________

Farmer Name 2: ______________________ Phone: ______________ Location: ____________________________

Farmer Name 3: ______________________ Phone: ______________ Location: ____________________________

Farmer Name 4: ______________________ Phone: ______________ Location: ____________________________

Who is collecting Castor in your district?

Collector Name 1: ______________________ Phone: ______________ Location: ____________________________

Collector Name 2: ______________________ Phone: ______________ Location: ____________________________

Collector Name 3: ______________________ Phone: ______________ Location: ____________________________

Collector Name 4: ______________________ Phone: ______________ Location: ____________________________

CROTON DATA

61. Is Croton megalocarpus growing in your district? Yes No
62. Is Croton being planted or growing wild or both? Plantations Wild Both
63. Are there active Croton plantations that have been planted within the past 5 years? Yes No
64. Is anyone actively harvesting Croton that is growing in the wild? Yes No
65. What percentage of farms in your district do you estimate are growing Croton?
    <1% 1-5% 5-10% 10-20% 20-50% 50-75% 75-100%
66. What is the total number of farms in your district? ________________
67. What is the potential for Croton in your district? Very Good Good Neutral Bad
68. What are the main obstacles to its development?
    Optimal Planting Material Market Agronomic Knowledge Other: __________________________
69. What areas in your district have the most Croton activity?
    ____

Who is growing Croton (try to get small, medium, and large scale producers to visit)?

Farmer Name 1: ______________________ Phone: ______________ Location: ____________________________

Farmer Name 2: ______________________ Phone: ______________ Location: ____________________________

Farmer Name 3: ______________________ Phone: ______________ Location: ____________________________

Farmer Name 4: ______________________ Phone: ______________ Location: ____________________________

Who is collecting Croton in your district?

Collector Name 1: ______________________ Phone: ______________ Location: ____________________________

Collector Name 2: ______________________ Phone: ______________ Location: ____________________________

Collector Name 3: ______________________ Phone: ______________ Location: ____________________________

Collector Name 4: ______________________ Phone: ______________ Location: ____________________________

JATROPHA DATA

70. Is Jatropha growing in your district? Yes No
71. Is Jatropha being planted or growing wild or both? Plantations Wild Both
72. Are there any active Jatropha plantations in your district? Yes No
73. What number of farms in your district do you estimate are growing Jatropha? ______________________
74. What is the total number of farms in your district? ____________________
75. What is the potential for Jatropha in your district? Very Good Good Neutral Bad
76. What are the main obstacles to its development?
    Optimal Planting Material Market Agronomic Knowledge Other: __________________________
77. What areas in your district have the most Jatropha activity?
    ____

Who is growing Jatropha (try to get small, medium, and large scale producers to visit)?
Farmer Name 1: ______________ Phone: ______________ Location: ______________
Farmer Name 2: ______________ Phone: ______________ Location: ______________
Farmer Name 3: ______________ Phone: ______________ Location: ______________
Farmer Name 4: ______________ Phone: ______________ Location: ______________
Farmer Name 5: ______________ Phone: ______________ Location: ______________
Farmer Name 6: ______________ Phone: ______________ Location: ______________
Farmer Name 7: ______________ Phone: ______________ Location: ______________
Farmer Name 8: ______________ Phone: ______________ Location: ______________

Endnotes

[i] Tim Padgett, "The Next Big Biofuel?" TIME MAGAZINE ONLINE, January 29, 2009, *available at* http://www.time.com/time/magazine/article/0,9171,1874835,00.html.
[ii] Sammy Cheboi, "Evil Tree Turns Out a Savior as Fuel Prices Bite," DAILY NATION, October 6, 2008.
[iii] "New Investments to Create 13,000 New Jobs," THE NEW VISION, April 6, 2009.
[iv] "Tree That Holds Solution to Fuel Crisis and Environmental Conservation," DAILY NATION, July 20, 2008.
[v] "Boosting Biofuels Without Compromising Food Security," IRIN, August 13, 2008.
[vi] J. Heller, *Physic Nut: Jatropha curcas L. Promoting the Conservation and Use of Underutilized and Neglected Crops*, International Plant Genetic Resources Institute (Rome: 1996).
[vii] J. Gressel, "Transgenics are Imperative for Biofuel Crops." PLANT SCIENCE 174 (2008): 246-263.
[viii] W.M.J. Achten et al., "*Jatropha* Bio-diesel Production and Use." BIOMASS AND BIOENERGY 32(12) (2008): 1063-1084.; R.E.E. Jongschaap et al., "Claims and Facts on *Jatropha curcas* L." PLANT RESEARCH INTERNATIONAL; K.D. Ouwens et al., "Position Paper on *Jatropha curcas*: State of the Art, Small- and Large-Scale Project Development" The Seminar Program Committee of FACT (Fuels from Agriculture in Communal Technology) Seminar, March 26-28 2007, Wageningen, the Netherlands; "Jatropha for Biodiesel is not a Miracle Crop," AFRICAN NEWS NETWORK, *available at* http://africanagriculture.blogspot.com/2009/04/jatropha-for-biodiesel-not-miracle-crop.html (accessed April 16, 2009).
[ix] E. Münch, "Die Purgiernuß (*Jatropha curcas* L.)," Botanik, Ökologie und Anbau, University of Hohenheim, (Stuttgart: 1986).
[x] Heller, *supra* Note 8.
[xi] Heller, *supra* Note 8.
[xii] Heller, *supra* Note 8.
[xiii] Heller, *supra* Note 8.
[xiv] Bijan Dehgan and Grady L. Webster, "Morphology and Infrageneric Relationships of the Genus *Jatropha* (Euphorbiaceae)," UNIV. CAL. PUBL. BOT., Vol. 74, p76 + 33 plates (1979).
[xv] J. Heller, *supra* Note 8; D.N. Tewari, *Jatropha & Biodiesel*, Ocean Books (P) Ltd. 9 (New Delhi: 2007).
[xvi] Tewari, *supra* Note 17.
[xvii] A. Kumar and S. Sharma. "An Evaluation of multipurpose Oil Seed Crop for Industrial Uses (*Jatropha* curcas L.): A Review." *Industrial Crops and Products* 2(2008): 1-10.
[xviii] Kumar, *supra* Note 19.
[xix] Kumar, *supra* Note 19.
[xx] Tewari, *supra* Note 17.
[xxi] Kumar, *supra* Note 19.
[xxii] Tewari, *supra* Note 17.
[xxiii] Kumar, *supra* Note 19.
[xxiv] 19% reported by G.D.P.S. Augustus, M. Jayabalan, and G.J. Seiler, "Evaluation and Bioinduction of Energy Components of *Jatropha Curcas*," *Biomass and Bioenergy* 23 (2002): 161-164; 22-42% reported by N. Sunil, K.S. Varaprasad, N. Sivaraj, T.S. Kumar, B. Abraham, and R.B.N. Prasad, "Assessing *Jatropha* curcas L. Germplasm in-situ – A Case Study," *Biomass and Bioenergy* 32(2008):198-202; 28-38.80% reported by N. Kaushik, K. Kumar, S. Kumar, N. Kaushik, and S. Roys, "Genetic Variability and Divergence Studies in Seed Traits and Oil Content of *Jatropha* (*Jatropha* curcas L.) Accessions," *Biomass and Bioenergy* 31(2007):497-502; 43-59 % reported by G.M. Gübitz, M. Mittelbach, and M. Trabi. "Exploitation of the Tropical Oil Seed Plant *Jatropha* curcas L," *Bioresource Technology* 67(1999): 73-82.
[xxv] Achten, *supra* Note 10.
[xxvi] Augustus, *supra* Note 26.
[xxvii] Heller, *supra* Note 8; Gübitz, *supra* Note 26;
ICRAF, "Agroforestry Tree Database: A Tree Species Reference and Selection Guide," <http://www.worldagroforestrycentre.org/sea/products> (17 May 2009).
[xxviii] Heller, *supra* Note 8; Achten, *supra* Note 10; Kumar, *supra* Note 19.
[xxix] Gübitz, *supra* Note 26.
[xxx] Achten, *supra* Note 10; Augustus, *supra* Note 26; Kumar, *supra* Note 19.
[xxxi] Gübitz, *supra* Note 26.

[xxxii] Kumar, supra Note 19; P. Sirisomboon, P. Kitchaiya, T. Pholpho, and W. Mahuttanyavanitch, "Physical and Mechanical Properties of *Jatropha* curcas L: Fruits, Nuts and Kernels," *Biosystems Engineering.* 97(2007):201-207.
[xxxiii]Gübitz, *supra* Note 26; Achten, *supra* Note 10.
[xxxiv] Achten, *supra* Note 10.
[xxxv] Gressel, *supra* Note 9.
[xxxvi] E. Buddenhagen, Charles Chimera, and Patti Clifford, "Assessing Biofuel Crop Invasiveness: A Case Study," *PLoS ONE* 4(4)e5261(April 2009):1-5.; Achten, *supra* Note 10.
[xxxvii] K. Openshaw, "A Review of *Jatropha* Curcas: an Oil Plant of Unfulfilled Promise," *Biomass and Bioenergy* 19(2000): 1-15.; Achten, *supra* Note 10; Gressel, *supra* Note 9.
[xxxviii] "Jatropha Curcas Plantations," *available at* http://www.jatrophacurcasplantations.com; "Jatropha Curcas – Physic Nut," *available at* http://www.tropilab.com/jatropha-cur.html; "Jatropha Seeds Exporters in India," *available at* http://www.tradeholding.net/default.cgi/action/viewproducts/productid/104021/productname/Jatropha_Seeds_Exporters_In_India.
[xxxix] Jongschaap, *supra* Note 10.
[xl] "Jatropha for Biodiesel is not a Miracle Crop," AFRICAN NEWS NETWORK, *available at* http://africanagriculture.blogspot.com/2009/04/jatropha-for-biodiesel-not-miracle-crop.html (accessed April 16, 2009); E.J. Trondsen, "Though Wonder Crop, Jatropha Won't Rid the World of Fossil Fuel Soon," THE EAST AFRICAN, April 13-19, 2009, at 25.
[xli] Ouwens, *supra* Note 10.
[xlii] Maes WH et al., "Climatic Growing Conditions of Jatropha curcas L.," BIOMASS AND BIOENERGY (2009), doi:10.1016/j. biombioe.2009.06.001.
[xliii] Maes, *supra* Note 44, at 3-4.
[xliv] Ouwens, *supra* Note 10.
[xlv] Heller, *supra* Note 8, referred to a range of 300-1,000 millimeters of rainfall, and mainly occurring at the altitude of 0-500 meters above sea level with a temperature range of 20-28°C. Tewari, *supra* Note 17, reports that *Jatropha* grows well in low rainfall condition (500 to 750 millimeters), but also tolerates higher rainfall (up to 1,200 millimeters) conditions. Tewari also noted that *Jatropha* tolerates annual temperature range of 18-38°C. Achten, *supra* Note 10, referred to a range of 250-3,000 millimeters rainfall and a temperature of 20-28°C, with a minimum of 500-600 millimeters of rainfall for production. M.M. Azam, A. Waris, and N.M. Nahar, "Prospects and Potential of Fatty Acid Methyl Esters of Some Non-traditional Seed Oils for Use as Biodiesel in India," *Biomass and Bioenergy*.29 (2005): 293-302, also referred to a range of 250-1,200 millimeters of rainfall.
[xlvi] Heller, *supra* Note 8; H.P.S. Makkar et al., "Studies on Nutritive Potential and Toxic Constituents of Different Provenances of Jatropha curcas," JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY 45 (1997): 3152-7; Tewari, *supra* Note 17.
[xlvii] Openshaw, *supra* Note 39; Tewari, supra Note 17; Augustus, supra Note 26; Gressel, *supra* Note 9.
[xlviii] C. Shanker and S.K. Dhyani, "Insect Pests of *Jatropha curcas* L. and the Potential for Their Management," CURRENT SCIENCE, Vol. 91 (2006): 162-3; "The Potential of *Jatropha curcas* in Rural Development and Environment Protection – An Exploration," Workshop Presentation, 13-15 May 1998, <http://www.jatropha.de/rf-conf1.htm> (10 April 2009); M. Benge, *Assessment of the Potential of Jatropha curcas for Energy Production and Other Uses in Developing Countries*, (July 2006) <http://www.echotech.org/mambo/index.php?option=com_docman&task=doc_view&gid=179> (12 December 2007); ICRAF, "Agroforestry Tree Database: A Tree Species Reference and Selection Guide."
[xlix] Tewari, *supra* Note 17.
[l] Tewari, *supra* Note 17.
[li] Heller, *supra* Note 8.
[lii] J.C. Silveira, "Contribution à l'étude du Pulghère aux îles du Cap Vert" INST. SUPER. AGRON. (Lisboa) 6(1) (1934):116-126. cited in Heller, *supra* Note 8. Rainfall data is from Achten, supra Note 10.
[liii] C. Naigeon, "Pourghère, graine de relance" INTER TROPIQUES 7(22)(1987):25-27, cited in Heller, *supra* Note 8. Rainfall data is from Achten, supra Note 10.
[liv] Ouwens, *supra* Note 10, cites a report by Barillas.
[lv] Achten, *supra* Note 10, cites G.D. Sharma, S.N. Gupta, and M. Khabiruddin, "Cultivation of Jatropha curcas as a future source of hydrocarbon and other industrial products," published in G.M. Gubitz, M. Mittelbach, M. Trabi, eds., "Biofuels and industrial products from Jatropha curcas, Proceedings from the symposium Jatropha 97," Managua, Nicaragua, February 23–27; Achten, *supra* Note 10.

[lvi] Achten, *supra* Note 10, cites personal communication with Kumar (2005).
[lvii] Achten, *supra* Note 10, cites personal communication with Kumar (2005).
[lviii] Ouwens, *supra* Note 10, cites a report by Patolia.
[lix] Ouwens, *supra* Note 10, cites a report by Manurung.
[lx] Achten, *supra* Note 10, cites personal communication with Busimans (2005).
[lxi] Openshaw, *supra* Note 39.
[lxii] Personal communication with Henning by Heller, *supra* Note 8.
[lxiii] L. Larochas, "Les huiles siccatives de l'industrie française," Le Pourghère Oléagineux 3(6/7)(1948):321-328, cited in Heller, *supra* Note 8. Rainfall data is from Achten, *supra* Note 10.
[lxiv] Achten, supra Note 10, cites N. Foidl, G. Foidl, M. Sanchez, M. Mittelbach, S. Hackel, "Jatropha curcas L. as a source for the production of biofuel in Nicaragua," *Bioresource Technology* 58(1996):77–82.
[lxv] Personal communication with Foidl by Heller, *supra* Note 8.
[lxvi] T. Matsuno, U. Ohsawa, H. Toyohara and K. Nishiyama, "Investigation of oil plants and characteristics of some oil plant seeds," J. AGRIC. SCI., 29(3)(1985):160-174. Rainfall data is from Achten, *supra* Note 10.
[lxvii] T.K. Loos, "Socio-Economic Impact of a Jatropha-Project on Smallholder Farmers in Mpanda, Tanzania; Case Study of a Public-Private-Partnership Project in Tanzania," Masters Thesis, INSTITUTE FOR AGRICULTURAL ECONOMICS AND SOCIAL SCIENCES IN THE TROPICS AND SUBTROPICS, HOHENHEIM: UNIVERSITY OF HOHENHEIM, 2009.
[lxviii] L. Messemaker, "The Green Myth? Assessment of the Jatropha Value Chain and Its Potential for Pro-poor Biofuel Development in Northern Tanzania," UTRECHT UNIVERSITY, 2008.
[lxix] W. Stienswat, S. Rattanaserikiat and S. Nimunchat, "The studies on growing of physic nut (*Jatropha curcas*) in the large test plot: Research reports on growing of physic nut (*Jatropha curcas*) for diesel fuel substitute," BANGKOK: KASETSART UNIVERSITY, 1986, cited in Heller, *supra* Note 8. Rainfall data is from Achten, *supra* Note 10.
[lxx] Achten, *supra* note 10, cites T.A. Tigere, T.C. Gatsi, I.I. Mudita, T.J. Chikuvire, S. Thamangani, and Z. Mavunganidze, "Potential of Jatropha curcas in improving smallholder farmers' livelihoods in Zimbabwe: An exploratory study of Makosa Ward, Mutoko District," JOURNAL OF SUSTAINABLE DEVELOPMENT IN AFRICA 8 (2006):1–9.
[lxxi] Messemaker, *supra* Note 69.
[lxxii] Messemaker, *supra* Note 69.
[lxxiii] Loos, *supra* Note 68.
[lxxiv] R. Orange, "Jatropha seeds yield little hope for India's oil dream," THE NATIONAL, May 11, 2009, *available at* http://www.thenational.ae/article/20090511/BUSINESS/705119944/1005 (accessed on May 12, 2009).
[lxxv] Orange, *supra* Note 75.
[lxxvi] Orange, *supra* Note 75.
[lxxvii] Augustus, *supra* Note 26; Azam, *supra* Note 46; D.K. Garnayak, R.C. Pradhan, S.N. Naik, and N. Bhatnagar, "Moisture-Dependent Physical Properties of *Jatropha* Seed (*Jatropha* curcas L.)" INDUSTRIAL CROPS AND PRODUCTS 27 (2008): 123-129.
[lxxviii] Jongschaap, *supra* Note 10.
[lxxix] *See* W. Gerbens-Leenes, A.Y. Hoekstra and T.H. van der Meer, "The Water Footprint of Bioenergy Crops," PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCE (Early Edition), April 20, 2009 (finding that one liter of oil requires 13,676, 14,201, and 19,924 liters of water for *Soy*, *Rapeseed*, and *Jatropha*, respectively); *but see* W. H. Maes, W. M. J. Achten, and B. Muys, "Use of Inadequate Data and Methodological Errors Lead to an Overestimation of the Water Footprint of *Jatropha curcas,"* PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCE (Early Edition), August 25, 2009; and R. E. E. Jongschaap, R. A. R. Blesgraaf, T. A. Bogaard, E. N. van Looa, and H. H. G. Savenije, "The Water Footprint of Bioenergy From *Jatropha curcas* L.," PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCE (Early Edition), September 1, 2009.
[lxxx] Trondsen, *supra* Note 42; Messemaker, supra Note 69.
[lxxxi] Openshaw, *supra* Note 39.
[lxxxii] Achten, *supra* Note 10.
[lxxxiii] Achten, *supra* Note 10.
[lxxxiv] Heller, *supra* Note 8; Achten, *supra* Note 10.
[lxxxv] Personal communication with Mr. Willis Atie and Mr. Fred Amolo, research officers of KEFRI Maseno office, on February 10, 2009.
[lxxxvi] Achten, *supra* Note 10.

[lxxxvii] Openshaw, *supra* Note 39.
[lxxxviii] Loos, *supra* Note 68.
[lxxxix] Trondsen, *supra* Note 42.
[xc] M. Ndurya and G. Kihara, "Canadian Company Eyes Tana Delta for Biofuel Projects," BUSINESS DAILY AFRICA, April 17, 2009.
[xci] F. Boerstler (2009): sources: land-use - GoK, FEWS-NET, WFP, Kenya Livelihood zones database used with special permission from WFP-Nairobi, agro-ecological zones adapted from Jaetzhold & Schmidt 1983, research areas - GPS-points Boerstler, administrative boundaries - CBS 2003.
[xcii] M. Sujatha, T.P. Reddy, M.J. Mahasi, "Role of biotechnological interventions in the improvement of castor (Ricinus communis L.) and Jatropha curcas L., BIOTECHNOLOGY ADVANCES 26 (2008) 424–435, 425.
[xciii] E.A. Weiss, *Castor, Sesame, and Safflower* (Leonard Hill, London 1971); "The Castor Bean," *available at* http://waynesword.palomar.edu/plmar99.htm#intro (*accessed* 23 February 2009).
[xciv] W.T. Parsons, *Noxious Weeds of Australia*, Second Edition, at 431 (CSIRO 2001).
[xcv] Dove Biotech, "Castor Bean (Ricinus Communis): An International Botanical Answer to Biodiesel Production and Renewable Energy," *available at* http://www.dovebiotech.com/pdf/CASTOR%20BEAN%20(RICINUS%20COMMUNIS)%20-%20BIODIESEL.pdf (*accessed* 24 February 2009).
[xcvi] R.D. Brigham, "Castor: Return of an Old Crop," p. 380-383, J. Janick and J.E. Simon (eds.), *New Crops*, (New York 1993).
[xcvii] Floridata, "Ricinis Communis," *available at* http://www.floridata.com/ref/R/rici_com.cfm (*accessed* 27 February 2009).
[xcviii] D. K. Salunkhe et al., *World Oilseeds: Chemistry, Technology, and Utilization*, at 513 (Springer 1992)
[xcix] Brigham, *supra* Note 97.
[c] B.S. Baldwin and R.D. Cossar, "Castor yield in response to planting date at four locations in the south-central United States," INDUSTRIAL CROPS AND PRODUCTS, Vol. 29, Issues 2-3 (March 2009) 316-319.
[ci] CastorOil, "Castor Oil as Biodiesel & Biofuel," *available at* http://www.castoroil.in/uses/fuel/castor_oil_fuel.html (*accessed* 25 February 2009).
[cii] Dove Biotech, *supra* Note 96.
[ciii] E.S. Oplinger et al., "Castorbean," *Alternative Crops Manual*, UNIVERSITY OF WISCONSIN, <http://www.hort.purdue.edu/newcrop/afcm/castor.html> (accessed 23 February 2009); M. Chinongoza, "Castor Bean for Biodiesel Production," <http://ezinearticles.com/?Castor-Bean-Oil-For-Biodiesel-Production&id=917729> (6 December 2007); "Castor," adapted from JOURNAL OF AMERICAN OIL CHEMISTS SOCIETY, vol. 65, no. 12 (1988), and A. Bonjean, "Le Ricin," <http://www.ienica.net/crops/castor.htm> (24 February 2009); "Cultivation technology of CASTOR (Ricinus communis L.)," *available at* http://krishisewa.com/articles/castor.html (*accessed* 26 February 2009).
[civ] H.L. Bhardwaj et al., "Evaluation of castor germplasm for agronomic and oil characteristics," from J. Janick (ed.), PROGRESS IN NEW CROPS, p. 342-346 (ASHS Press 1996).
[cv] Commodity Watch, "Castor Seed Holds Promise," *available at* http://www.commoditywatch.in/index.php?action=show_full_story&content_id=950 (*accessed* 24 February 2009).
[cvi] "Cultivation Technology of Castor (Ricinus communis L.)," *available at* http://krishisewa.com/articles/castor.html (accessed 2 March 2009).
[cvii] California Invasive Plant Council, "California Invasive Plant Inventory," *available at* http://www.cal-ipc.org> (*accessed* 24 March 2009).
[cviii] Purdue University, Center for New Crops and Plants Database, "Ricinus Communis L," J.A. Duke, *Handbook of Energy Crops* (1982), *available at* <http://www.hort.purdue.edu/newcrop/duke_energy/Ricinus_communis.html#Yields%20and%20Economics> (*accessed* 24 February 2009).
[cix] AFRICA BIOFUEL AND EMISSION REDUCTION COMPANY, "Are all Biofuels Green by Definition?" *available at* http://www.africabiofuel.com/The_Product.aspx> (*accessed* 24 February 2009).
[cx] L.H. Zimmerman et al., "Castorbeans in California" CALIF. AGR. EXPT. STA., Davis, 468 (1958).
[cxi] U.S. Centers for Disease Control & Prevention, "Questions and Answers About Ricin," *available at* http://www.bt.cdc.gov/agent/ricin/qa.asp (*accessed* 25 February 2009).
[cxii] T.A. McKeon et al., "The Enzymology of Castor Oil Biosynthesis," from ISSUES IN NEW CROPS AND NEW USES, J. Janick and A. Whipkey (eds.) (ASHS Press 2007).
[cxiii] U.N. Food & Agriculture Organization (FAO), Eco Crop Database (http://ecocrop.fao.org/ecocrop/).

[cxiv] N.E. Bassam, *Energy Plant Species: Their Use and Impact on the Environment and Development*, 125 (Earthscan 1998); V. Scholz and J. Nogueira da Silva, "Prospects and Risks of the Use of Castor Oil as a Fuel," *Biomass and Bioenergy* 32 (2008) 95-100, 96.
[cxv] Medors Biotech, "Ecological Requirement of Castor*," available at* http://www.medorsbiotech.com/ecology2.htm (*accessed* 4 March 2009).
[cxvi] Indian Ministry of Communications and Information Technology, National Informatics Centre, "Pests and Diseases of Castor," *available at* http://www.ap.nic.in/oilseeds/Cpests.html; adapted from the JOURNAL OF AMERICAN OIL CHEMISTS SOCIETY, vol. 65, no. 12 (1988), *available at* http://www.ienica.net/crops/castor.htm (*accessed* 24 February 2009).
[cxvii] Brigham, *supra* Note 97.
[cxviii] FAO, FAOSTAT Database, *available at* http://faostat.fao.org (*accessed* 23 February 2009).
[cxix] FAO, *supra* Note 119.
[cxx] Medors Biotech, *supra* Note 116.
[cxxi] Brigham, *supra* Note 97.
[cxxii] Duke, *supra* Note 109.
[cxxiii] Density is based on test results performed as part of this study.
[cxxiv] C.M. Ngari et al., "Castor production," KENYA AGRICULTURAL RESEARCH INSTITUTE, 2006.
[cxxv] Brigham, *supra* Note 97; "Cultivation Technology of Castor," *available at* http://www.krishisewa.com/articles/castor.html (accessed 24 February 2009).
[cxxvi] Medors Biotech, *supra* Note 116 (claiming that Thiram fungicide is the only registered seed treatment for Castor); "Cultivation Technology of Castor," *supra* Note 126.
[cxxvii] Medors Biotech, *supra* Note 116.
[cxxviii] S.P. Palaniappan and K. Sivararum, *Cropping Systems in the Tropics*, at 63 (New Age International 2006).
[cxxix] P. Padmavathi and C.V. Raghavaiah, "Productivity and Returns of Castor (Ricinus communis)-Based Intercropping Systems with Pulses and Vegetables Under Rainfed Conditions," INDIAN JOURNAL OF AGRICULTURAL SCIENCE, 2004, vol. 74, nº5, pp. 235-238.
[cxxx] PHILIPPINES COUNCIL FOR AGRICULTURE, FORESTRY AND NATURAL RESOURCES RESEARCH AND DEVELOPMENT, AGROFORESTRY INFORMATION NETWORK, *Sloping Agricultural Land Technology (SALT-1): A Guide on How to Farm Your Hilly Land Without Losing Your Soil*, *available at* http://www.pcarrd.dost.gov.ph/cin/AFIN/technologies%20-%20salt1.htm> (*accessed* 24 February 2009).
[cxxxi] Ngari, *supra* Note 125.
[cxxxii] Brigham, *supra* Note 97.
[cxxxiii] Dove Biotech, *supra* Note 96.
[cxxxiv] Dove Biotech, *supra* Note 96.
[cxxxv] Dove Biotech, *supra* Note 96.
[cxxxvi] FAO, *supra* Note 119.
[cxxxvii] "Futures Watch – Castor Seed," *available at* http://www.commodityonline.com/FuturesWatch/future-spotrates.php?selcmdty=4898 (*accessed* 23 February 2008).
[cxxxviii] FAO, *supra* Note 119.
[cxxxix] FAO, *supra* Note 119.
[cxl] ICRAF, AGROFORESTRY TREE DATABASE, *available at* http://www.worldagroforestrycentre.org/sea/products/ (accessed 2 April 2009)
[cxli] A.R. Smith, "Flora of Tropical East Africa," ed. R.M. Polhill, *Eupohorbiaceae (Part 1),* (1987) (explaining that *Croton megalocarpus* closely resembles *Croton mubango* Muell. arg. from Zaire and Angola.
[cxlii] P. Maundu and B. Tengnas, "Useful Trees and Shrubs for Kenya: Technical Handbook No. 35," ICRAF; ICRAF, *supra* Note 141.
[cxliii] ICRAF, *supra* Note 141.
[cxliv] Maundu, *supra* Note 143.
[cxlv] Maundu, *supra* Note 143.
[cxlvi] T. Noad and A. Birnie, "Trees of Kenya," available at http://www.nbhs.com/trees_of _Kenya_tefno_34280.html (accessed April 2009).
[cxlvii] ICRAF, *supra* Note 141.

[cxlviii] U.S. Forest Service (USFS), Center for Wood Anatomy Research, "Technology Transfer Factsheet," http://www.fpl.fs.fed.us/techsheets/chudnoff/African/new_html_docs/crotonmegalocarpus.html (accessed April 3, 2009)
[cxlix] ICRAF, *supra* Note 141.
[cl] The Wood Explorer, "The Wood Explorer Database," *available at* http://www.thewoodexplorer.com/maindata/we351.html (accessed April 3, 2009).
[cli] *Endelevu Energy and Energy for Sustainable Development Africa,* A Roadmap for Biofuels in Kenya: Opportunities & Obstacles *(Gesellschaft für Technische Zusammenarbeit & Kenya Ministry of Agriculture 2008).*
[clii] The Wood Explorer, *supra* Note 151.
[cliii] Maundu, *supra* Note 143.
[cliv] ICRAF, *supra* Note 141.
[clv] ICRAF, *supra* Note 141; Kakamega Environment Education Programme (KEEP), *available at* http://www.columbia.edu/cu/e3b/conservation/KEEP/index.html (accessed April 3, 2009).
[clvi] I. Addae-Mensah, H. Achenbach, G.N. Thoithi, R. Waibel and J.W. Mwangi, "Epoxychiromodine and other constituents of Croton megalocarpus," CONSTITUENTS OF TROPICAL MEDICINAL PLANTS, Vol. 31 (2006), No. 6, at 2055.
[clvii] I. Addae-Mensah, R. Waibel, H. Achenbach, G. Muriuki, C. Pearce and J.K.M. Sanders, "A Clerodane diterpene and other constituents of Croton megalocarpus" CONSTITUENTS OF TROPICAL MEDICINAL PLANTS, Vol. 28 (2006), No. 10, at 2759-2761
[clviii] Addae-Mensah, *supra* Notes 157 and 158; W.S. Abdel Gadir, T.O. Onsa, W.E.M. Ali, S.M.A. El Badwi and S.E.I. Adam, "Comparative toxicity of Croton macrostachys, Jatropha curcas and Piper abyssinica seeds in Nubian goats," SMALL RUMINANT RESEARCH 48 (2003) 61-67.
[clix] N. Radulovic, E. Mananjarasoa, L. Harinantenaina and A. Yoshinori, "Essential oil composition of four Croton species from Madagascar and their chemotaxonomy," BIOCHEMICAL SYSTEMATICS AND ECOLOGY 34 (2006) 648-653.
[clx] R. Thijssen, ETC-Kenya Consultants, "Croton megalocarpus, the poultry-feed tree: how local knowledge could help to feed the world," *available at* http://www.fao.org/docrep/w3735e29.html (accessed April 3, 2009)
[clxi] G.F. Townsend, "Multi-Purpose Trees for Honey Production," *available at* http://www.echonet.org (accessed April 2, 2009)
[clxii] ICRAF, *supra* Note 141.
[clxiii] ICRAF, *supra* Note 141.
[clxiv] ICRAF, *supra* Note 141.
[clxv] L. Milich, "Environmental Comparisons of Croton megalocarpus vs. Other Tropical Feedstocks," *available at* http://www.africabiofuel.com/files/B)%feedstocks.pdf (accessed April 2, 2009)
[clxvi] ICRAF, *supra* Note 141.
[clxvii] AFRICA BIOFUEL AND EMISSION REDUCTION COMPANY, "The Biharamulo Biofuel Project," World Institute for Leadership and Management in Africa, Washington DC, *available at* www.wilma.us (accessed April 3, 2009).
[clxviii] AFRICA BIOFUEL AND EMISSION REDUCTION COMPANY, *supra* Note 168.
[clxix] ICRAF, *supra* Note 141.
[clxx] R. Thijssen, ILEAIA Newsletter, Vol. 11 No. 3, at 20.
[clxxi] Maundu, *supra* Note 143.
[clxxii] ICRAF, *supra* Note 141.
[clxxiii] ICRAF, *supra* Note 141; Maundu, *supra* Note 143.
[clxxiv] Personal communication with KEFRI experts on silviculture and breeding (April 4, 2009)
[clxxv] ICRAF, *supra* Note 141.
[clxxvi] ICRAF, *supra* Note 141.
[clxxvii] Thijssen, *supra* Note 171.
[clxxviii] USFS, *supra* Note 149.
[clxxix] Maundu, *supra* Note 143.
[clxxx] Thijssen, *supra* Note 161.
[clxxxi] Thijssen, *supra* Note 161; personal communications with farmers and field extension officers.
[clxxxii] ICRAF, *supra* Note 141.
[clxxxiii] ICRAF, *supra* Note 141.
[clxxxiv] ICRAF, *supra* Note 141.

[clxxxv] FAO, "Indigenous multi-purpose trees of Tanzania: uses and economic benefits for people," *available at* http://www.fao.org/docrep/X5327e/x5327e0w.html (accessed April 2, 2009)
[clxxxvi] Milich, *supra* Note 166.
[clxxxvii] F. Cabbage et al., "Timber investment returns for selected plantations and native forests in South America and the Southern United States," NEW FORESTS 33 (2007):237–255, 247.
[clxxxviii] J. Angaine, Kenya Forestry Seed Centre.
[clxxxix] U.S. Dept. of Agriculture, "Global Conference on Agricultural Biofuels: Research and Economics," *available at* http://www.ars.usda.gov/meetings/Biofuels2007 (accessed April 3, 2009)>
[cxc] The Gender and Governance Programme in Kenya, "Women from the semi-arid Nyeri North profit from alternative source of energy," *available at* http://www.gendergovernancekenya.org/featured/145 (accessed April 4, 2009)>
[cxci] KEEP, *available at* http://www.columbia.edu/cu/e3b/conservation/KEEP/index.html (accessed April 3, 2009).
[cxcii] Croton Research Network, University of Wisconsin, *available at* http://www.botany.wisc.edu/croton (accessed April 5, 2009)
[cxciii] AFRICA BIOFUEL AND EMISSION REDUCTION COMPANY, *supra* Note 168.
[cxciv] H. Stewart, "Micro-trigeneration's new design has potential to neutralize your home's energy impact," *available at* http://www.renewablechoice.com/blog-carbon-neutral-home-power-081224.html.
[cxcv] DIN 51605, Kraftstoff fur pflanzenoltaugliche Motoren—Rapsolkraftstoff—Anforderungen. Vornorm, Deutsches Institut fur Normung e.V., 2005.
[cxcvi] KS-1309-1: 2003.
[cxcvii] ASTM D6751-07b. There are two standards for sulfur content in the US, 15 ppm for on-road use, and 500 ppm for off-road applications. Methanol content standard is either 0.2 % mass or a flashpoint less than 130 degrees Celcius.
[cxcviii] EN 14214:2008. The EU test for carbon residue is based on a 10% distillation sample, as opposed to the tests in the US and Brazil, which are based on a 100% sample.
[cxcix] ANP 42.
[cc] Draft (Feb. 2009).
[cci] KS-1309-1: 2003.
[ccii] M.C.G. Albuquerque, "Properties of biodiesel oils formulated using different biomass sources and their blends," Renewable Energy 34 (2009) 857–859; Flórez J.P. Nieto, N.A., Londoño, N.Y., Barajas, C.L. Proceso Experimental de Producción y Operación del Biocombustible obtenido partir del Aceite de Ricino. Tesis. Universidad Francisco de Paula Santander. (2004).
[cciii] ELSBETT GMBH, "Vegetable Oil Standard," *available at* http://www.elsbett.com/us/vegetable-oil/vegetable-oil-standard.html (accessed 11 March 2009).
[cciv] U.S. Dept. of Commerce, National Institute of Standards and Technology, "White Paper on Internationally Compatible Biofuels Standards," (Dec. 31, 2007).
[ccv] U.S. Dept. of Commerce, National Institute of Standards and Technology, "White Paper on Internationally Compatible Biofuels Standards," (Dec. 31, 2007).
[ccvi] U.S. Dept. of Commerce, National Institute of Standards and Technology, "White Paper on Internationally Compatible Biofuels Standards," (Dec. 31, 2007).
[ccvii] National Fire Protection Association, *available at* http://www.nfpa.org (accessed 10 March 2009).
[ccviii] U.S. Dept. of Commerce, National Institute of Standards and Technology, "White Paper on Internationally Compatible Biofuels Standards," (Dec. 31, 2007).
[ccix] Castor Oil, "Castor Oil as Biodiesel and Biofuel," *available at* http://www.castoroil.in/uses/fuel/castor_oil_fuel.html (accessed 10 March 2009).
[ccx] Engineer's Edge, "Fluid Characteristics Chart/ Data, Density, Vapor Pressure & Viscosity," *available at* http://www.engineersedge.com/fluid_flow/fluid_data.htm (accessed 10 March 2009).
[ccxi] Carmen Leonor and Barajas Forero, "Biodiesel from castor oil: a promising fuel for cold weather," Department of Hydraulic, Fluids and Thermal Sciences, Francisco de Paula Santander University.
[ccxii] U.S. Dept. of Commerce, National Institute of Standards and Technology, "White Paper on Internationally Compatible Biofuels Standards," (Dec. 31, 2007).
[ccxiii] Elsbett GmbH, "Vegetable Oil Standard," *available at* http://www.elsbett.com/us/vegetable-oil/vegetable-oil-standard.html (accessed 11 March 2009).
[ccxiv] U.S. DEPT. OF COMMERCE, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, "White Paper on Internationally Compatible Biofuels Standards," (Dec. 31, 2007).

[ccxv] H. Prankl and M. Worgetter, "Influence of the iodine number of biodiesel to the engine performance," ASAE (1996).
[ccxvi] U.S. DEPT. OF COMMERCE, *supra* Note 215.
[ccxvii] U.S. DEPT. OF COMMERCE, *supra* Note 215.
[ccxviii] T. Bryan, "Absorbing It All," BIODIESEL MAGAZINE (MARCH 2005), *available at* http://www.biodieselmagazine.com/article.jsp?article_id=239.
[ccxix] G. Kenreckhttp, "Improving Biodiesel Stability With Fuel Additives," Biodiesel Magazine (February 2007), *available at* http://www.biodieselmagazine.com/article-print.jsp?article_id=1443.
[ccxx] MANITOBA HYDRO LABORATORIES, "Biodiesel Test Glossary," *available at* http://www.hydro.mb.ca/your_business/mhl/bio_glossary.shtml.

Deutsche Gesellschaft für
Technische Zusammenarbeit (GTZ) GmbH

– German Technical Cooperation –

Dag-Hammarskjöld-Weg 1-5
65760 Eschborn/Germany
T +49 6196 79 2438
F +49 6196 79 802438
E jutta.schmitz@gtz.de
I www.gtz.de