DEG JATROPHA SUPPORT PROGRAMME

Pipal Limited

THE ECONOMIC VIABILITY OF GROWING JATROPHA CURCAS AS A SUSTAINABLE BIOFUEL FEEDSTOCK IN EAST AFRICA

David Lebun and Joseph Kiptoo taking germination data at
Saffron Energy Ltd., Laikipia, 2009

FINAL REPORT

MAY 2012

Contributors to the project, report and accompanying documents

The Partners and dedicated on-site agronomists laying out trials and taking measurements

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Jatropha Pests and Diseases specialist, *Beryn Otieno*, KEFRI – section on pests and diseases and pest identification cards
Beehives, pollination and bee keeping advice has been supplied by *Ernest Simeoni* of African Beekeepers, with the support of *Tom Masao* in Tanzania.

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Farid Mohamed – Director Pipal Ltd, contribution to financial models.
Sue Canney Davison – Director Pipal Ltd, project management and overall writing and compilation.

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Section One: The prevailing context of the project and selected biofuel feedstock

The background to the project

The Jatropha Support Programme (JSP) is a private public partnership project co-financed by Deutsche Investitions- und Entwicklungsgesellschaft (DEG) with funds from the German Ministry for Economic Cooperation and Development and nine East African companies. These parties found a complementary set of interests.[1].

Private companies in East Africa continue to face the challenge of increasingly expensive and sometimes unavailable energy to power their farms, equipment, processing units and vehicles. There is mounting acceptance of the need to find a much wider range of fuels to meet the increasing energy demands of a growing global population, to meet the needs of many in developing countries still without access to modern energy alternatives, and to meet the global demand for substantially lowering CO_2 emissions from burning fossils fuels, which are both the primary source of energy worldwide and which are increasingly expensive to extract, transport and deliver.

In 2007, when the project was conceived, jatropha was being lauded as a wonder biofuel crop that could grow on marginal soils in arid and semiarid areas. One of the primary factors in its promotion remains the fact that the oleo-chemistry of straight and transesterified jatropha vegetable oil allows it to be used in a much wider range of temperature and engine conditions than many other primary and secondary biodiesel feedstocks, and that along with camelina and algae, it is one of the main natural oils suitable for aviation kerosene.

The aim of this DEGJSP programme has been to give an informed response to the question: 'Under what conditions is it economically viable to grow jatropha as a commercially sustainable biofuel feedstock in East Africa?' In line with the prevailing wisdom, the benefits of the DEGJSP project were projected to be: potentially bringing more marginal lands into cultivation; the development of optimal cultivation and production processes for jatropha; and the promotion of a low-emission fuel that could contribute to the mitigation of climate change.

At the start of the project, preliminary results for Central American and Indian trials were beginning to challenge the hype. The only jatropha seed available was wild or virtually wild, and many of the necessary basic cultivation practices were just beginning to be understood and tested. Four years later, while many projects and start-up companies have come and gone, some scientists and companies still remain seriously engaged in looking at each aspect of the production value chain, from seed production to the development and delivery of all related products. They are engaged in the long process of deeply understanding the plant, what it is capable of providing, and under what conditions.

In this project, provenance, spacing and pruning, agronomy, micronutrient, economic, and pest and diseases trials were conducted at nine agro-ecologically different sites located 2000 km apart. This was to gain some practical results as the basis for future investment. The provenance trials used 22 different accessions planted in plots consisting of 9 plants each, and which were replicated five times. Most of the trials were planted under potentially limiting or fair agro-climatic conditions, both in terms of minimum temperatures and average rainfall patterns. At many sites, initial growth was restricted by the 2009 drought. The establishment and performance of these trials was monitored over a three-year period. Some basic observations from the data collected are shared in the first half of this report. Jatropha takes five to six years to mature, so any discussion of potential yields, harvesting, processing, commercial sustainability, social, environmental, and regulatory data rests on

[1] A brief description of the project set-up is in Annex one.

discussions with and feedback from other practitioners, as well as extensive background desk research.

Certain facts about the project are important to bear in mind when placing any findings within the context of the now extensive literature and activities on *Jatropha curcas Lin.* In most cases, the participating companies owned and chose the trials sites on existing working farms. The aim has been to gather as much information as possible within the three-year period as a basis for future commercial decision making. The trees may or may not be left in place depending on the needs of the companies.

The energy situation in East Africa

The sum total of all the countries in Sub-Saharan Africa generate about the same amount of power as Spain, and 2/3 of this capacity is in South Africa (Eberhard, 2010). With only 23% of the overall population benefiting from electricity and 83% of rural households doing without, Sub-Saharan Africa has the lowest electrification rates in the world (Boerstler, 2010). Only 2% of rural Tanzanians have access to electricity. If South Africa is excluded, Sub-Saharan Africa is the only region in the world where electricity consumption is falling. Almost all un-electrified homes rely on wood biomass for cooking and on kerosene for lighting. Some forecast that charcoal use will increase with population growth, until at least 2030. Africa faces rising population and the effects of climate change, and the (inefficient) production of charcoal remains one of the few sources of rural income. There is an urgent need to provide alternatives to the region's very high dependence on wood biomass. Predominant reliance on open wood fires contributes to extensive deforestation. The time, energy and physical costs of collecting wood fuel are borne mostly by women and children. Many chronic diseases result from indoor air pollution from inefficient cooking methods and stoves. With an estimated 800,000 children dying each year from acute lower respiratory diseases, internal air pollution is the highest cause of morbidity and mortality in children under five. It is responsible for more deaths than malnutrition, diarrhoea or childhood disease (Boerstler, 2010).

Taken together, these factors mean that the health, education, gender, and environmental Millennium Development Goals are unlikely to be met in Sub-Saharan Africa unless rural communities have access to cleaner modern energy and fuel. Despite the obvious depth and massive scale of the crisis and its negative effects on rural lives and on African flora and fauna, only now are clean cook stove alliances being formed and a concerted effort being made to find solutions.

Electricity costs in Sub-Saharan Africa are twice those in most developing countries. Because of unreliable supply and frequent power cuts, even those who are connected to the grid are often forced to buy diesel generators as back ups. This particularly applies to industries seeking a steady reliable supply of electricity to keep their processes going. Even in countries such as Kenya, which includes some hydro and geothermal power in its main grid, the high costs associated with the limited and unreliable distribution system continuously challenges investors and producers.

Access to and the cost of liquid fuels entail the same problems of uncertain availability, as well as considerable price fluctuations around a steadily rising trend line that lies above the world average. Not only do higher global fuel prices increase the percentage of US maize, vegetable oil, and sugar used for biofuel, pushing up food prices, but rising fossil fuel prices also mean higher fertilizer prices, higher costs for irrigation and other farm inputs, and higher costs for transportation to destination markets. One example: increased shipping costs for Sub-Saharan horticultural products into European markets. Against a vocal environmental lobby that frequently protests Kenya's horticultural exports, for example, processing using 'green' energy and flying using 'green' jet fuel could prove a bonus.

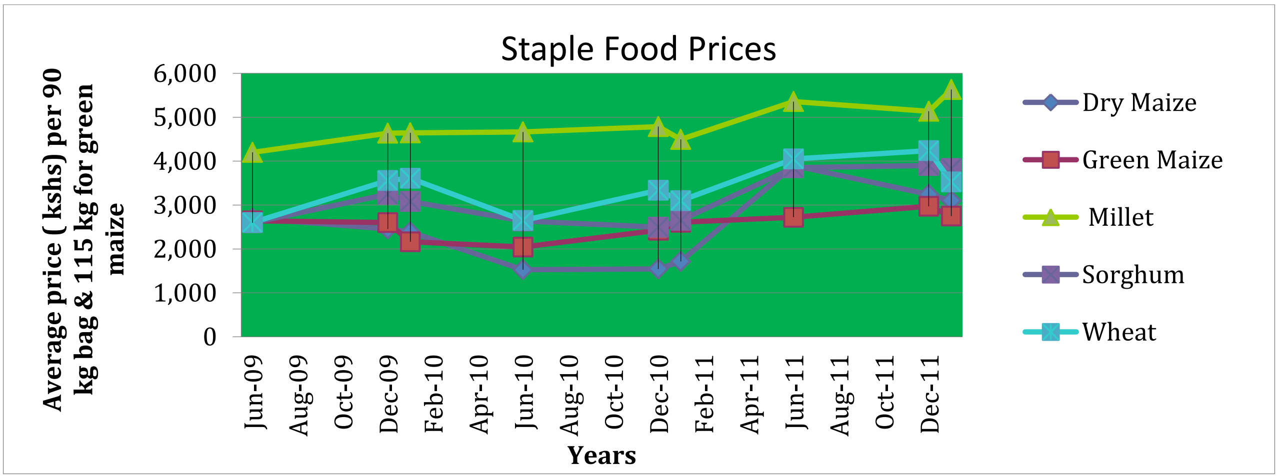
Maize prices in Uganda increased 114% between April 2010-2011 (World Bank Food Price Watch April 2011). Despite recent oil and gas finds (which remain to be exploited) and Kenya's increasing focus on exploiting coal and geothermal, the region is still predominantly dependent on using foreign exchange to import liquid fossil fuels, and so is subject to fluctuating exchange rates (Ministry of Energy, 2011).

In East Africa, the prices of staple foods and fuel are rising while still displaying seasonal and global variations, respectively (see Table 1 and Figure 1). While the DEGJSP study did not displace any food crops, sharply rising populations, increasingly unpredictable weather patterns, and generally low crop yields mean that care must be taken to ensure that food productivity rises alongside any large-scale biofuel developments on fair or optimal lands.

Table 1. Staple food prices in Kenya during the project*

CROP	Jun-09	Dec-09	Jan-10	Jun-10	Dec-10	Jan-11	Jun-11	Dec-11	Jan-12
Dry Maize	2,700	2,457	2,387	1,529	1,545	1,717	3,900	3,243	3,100
Green Maize	2,643	2,600	2,165	2,043	2,425	2,609	2,722	2,971	2,750
Millet	4,200	4,638	4,644	4,664	4,786	4,495	5,356	5,136	5,631
Sorghum	2,597	3,245	3,081	2,636	2,497	2,651	3,850	3,900	3,831
Wheat	2,600	3,560	3,608	2,650	3,336	3,100	4,050	4,238	3,525

* Kshs/90 kg bag except Green Maize 115kg bag



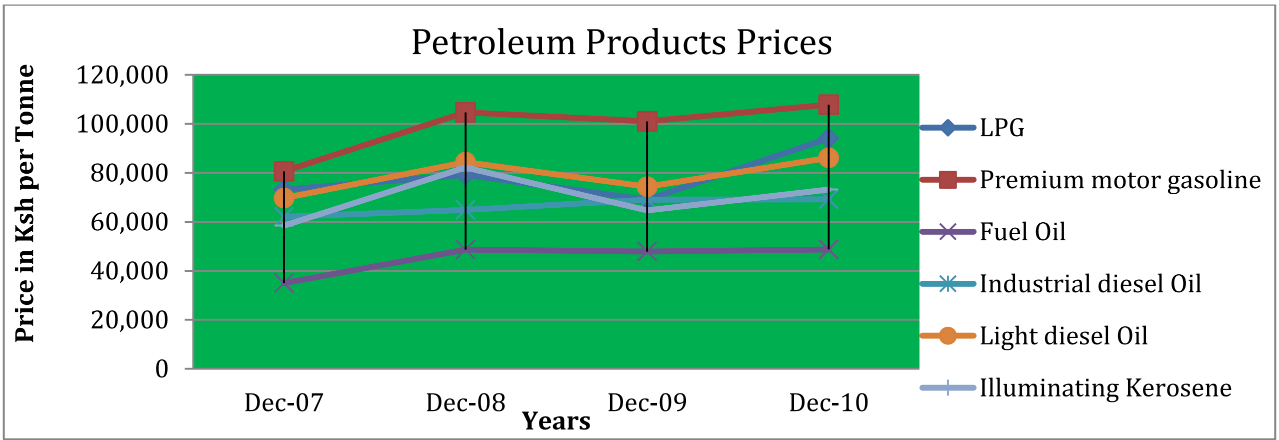


Figure 1. Food and Fuel prices in Kenya during the project and between December 2007–December 2010 respectively.

For all the reasons above, it has been and remains important to investigate the potential for using an adaptable perennial oleaginous tree grown on marginal lands with minimal inputs that can provide sufficient yields of a highly accessible straight vegetable oil/biodiesel for use in transport and standing diesel generators in East Africa.

The changing global perceptions and fortunes of *Jatropha* curcas

In 2006/2007, despite talk about establishing huge plantations and projects, there had been little actual research into jatropha yields under various conditions. No one was able to solidly refute the hype that jatropha could be commercially productive on marginal soils in semi-arid conditions. The unrealistic hype, unfavourable locations, poor management of initial funds, and all-too-often limited knowledge about Africa's agro-ecological realities resulted in many large-, medium- and small-scale projects coming and going during this period, from Ethiopia all the way through East Africa, as well as in Zambia and Mozambique (Hawkings and Chen, 2011). The results of our project indicate that most available *Jatropha curcas* varieties need optimal soils, temperature regimes and rainfall patterns (or specific mitigating set-up circumstances) to be commercially sustainable.

As the 'land grabbing', 'food for fuel' debate started to gain momentum in 2008, the German government was cautious about investing in a biofuel Private/Public Partnership. However, this kind of partnership and resulting viability trials were exactly what the OECD countries and other multilateral donors were calling for to bring commercial reality to the hype, and so a decision was made to move forward with the project.

In 2012, jatropha is still very much in the process of being domesticated and adapted to different agro-climatic conditions. Some (Volckaert, 2009) have predicted a 106% increase in yield by 2018, of which 62% would come from improved agronomic practices and the rest from selection and breeding. Work being done by serious researchers, and on well-run plantations (e.g., Sunbiofuels, Mozambique) and within smallholder and out-growers' schemes (e.g., D1 Oils, Zambia) that have access to appropriate agronomic knowledge, good locations, and that are supported with adequate financing, are still working to prove the commercial case. There are other smaller projects that entail low opportunity costs and which were set up to support communities and provide rural incomes. These include Kakute Ltd, Diligent Oils, Tatedo in Tanzania, and Biocarburant in Mali. These continue as model projects that have so far presumably managed to absorb annual variations in jatropha yields.

The project inception

Following on from a successful workshop held by DEG on 26th October 2006, DEG initiated a Jatropha Support Programme (JSP) with a view to promoting investments in the commercial production of jatropha seeds, oil, biodiesel and related activities (hereinafter commonly referred to as jatropha production) in East Africa.

The companies

The companies in this programme were interested in discovering if small- to medium-sized jatropha plantations could support their own energy needs. Of the two sites with workable agro-climatic conditions, one is on an unmanaged farm and the other suffered two years of severe drought. Therefore, the cost-benefit analysis below related to planting a 500-hectare site to jatropha in order to support a company's own fuel needs is based on an extrapolation from what we have learnt. The pilot project targeted companies with which DEG either has a current relationship or may form a relationship to co-finance such investments in the future. In almost all cases, the 10 hectares of land the companies were able to dedicate to the project were located close to their existing operations, which are predominantly in Central Kenya. Trial site locations were thus chosen purely for pragmatic reasons. The table below gives some details of the locations of each company site.

The site locations[2]

Company Name and Location	Altitude masl.	Average Rainfall mm p.a.	Annual temperature Min	Max	Mean	Normal Commercial jatropha production potential
Kenya						
REA Vipingo Plantations Ltd -Kilifi	45	1200	22	37	24.5	Optimal/Fair
Kofinaf Company Ltd-Thika	>600	970	8	31	25	Limiting – Dry/Cold
Tropical Farm Management (Kenya) Ltd -Makuyu	1500-1750	900-1020	8	31	24	Limiting – Cold
Lesiolo Grain Handlers Ltd. (LGHL)-Nakuru Small-scale extension in Bungoma	1950 1400	700-965 1100-1300	18 11	30 32	21.5 21.5	Limiting – Dry Fair
Kordes Roses East Africa (Kenya)-Nairobi with Saffron Energy Ltd Kenya- Laikipia	1850	525	12	32	16	Limiting – Dry/Cold
Vegpro Kenya-Naivasha Economic trials in Kibwezi	1750 1900	450-770 400	6 17.5	32 31	24 24	Limiting – Dry/Cold Limiting – Dry
Tanzania						
Minjingu Mines and Fertilizer Ltd.-Manyara	1200-1400	500-700	15	37	25	Limiting – Dry
Tanganyika Wattle Company Ltd.-Mbeya	1800	1100	-6	27	16.5	Limiting – Very cold, long dry season
Uganda						
Multiple Hauliers (EA) Ltd-Masindi	1158	1100-1400	16.8	30.1	25	Optimal/Fair

The outputs created

- Final report
- www.degjsp.com web site.
- Pest and Diseases identification cards
- Smallholder jatropha poster
- Smallholder Farmer's Handbook
- Liquid Biofuel policy and Activities in Africa (published by Practical Action 2010)
- Other small reports on website
- The project manager contributed to: Kenya Liquid Biofuel Strategy 2012-2015, Kenya National Biofuel Policy/Strategy (Draft) May 2011, 'Environmental Suitability and Agro-environmental Zoning of Kenya for Biofuel Production', published by ACTS/PISCES/UNEP

[2] A short site by site description is given in Annex Two

Background to the plant and general observations concerning its potential

Some facts about *Jatropha curcas*:

- Monecious perennial deciduous shrub with flowers in racemes in a diachasmal cyme pattern.
- Female to male flower number and ratios increase and decrease, respectively, leading to increasing fruiting as the plant matures at 5-6 years.
- The plant can survive up to 50 years.
- It can survive on 300 mm rainfall per year, bear some fruit with 600 mm, but needs over 950 mm per year at the right times for successful adaptation.
- It is sensitive to temperatures below 15^0 C, shade, wind speed, and evaporation.
- It has high phenological adaptability and environmental sensitivity.
- It does well in deep loose soils, rich in nitrogen, phosphorous and other key elements.
- The deep taproot may draw water to the surface and lateral roots may assist in controlling soil erosion.
- So far, very few projects are commercially sustainable.
- The straight vegetable oil from the seeds can be used in adapted lamps, stoves and engines.
- It is one of the few biological feedstocks suitable for aviation fuel and 'Bio-kerosene'.

The results of this project suggest that, at this point, the basis of potential commercial success rests on rain-fed jatropha in potentially optimal agro-climatic conditions. It will also assume reliable high quality (true-to-type) seeds, planted at the right time and managed with appropriate agronomic practices. Temperatures, rainfall, atmospheric humidity and altitude all affective jatropha productivity, and an informed choice of a plantation site will reflect a balanced set of cost/benefit and risk assessments inclusive of a range of factors. As seen above, most of the DEGJSP sites were not in optimal agro-climatic zones for jatropha, resulting in poor performance.

General East African agro-climatic conditions and potential

Maps based on average annual temperature and rainfall patterns do not capture the seasonality that limits the window for commercial jatropha set-up and long-term viability.[3] Some potential was witnessed in normally limiting conditions due to East Africa's erratic weather, and a few well-funded and serious research companies are working on different ways to improve jatropha yield and 'stretch' the plant. As a result, conservative variables were chosen to demonstrate the seasonality of planting windows, given that generic maps have very low actual predictive value.

1. Temperature-
    - Potentially optimum – 20° C - 32° C
    - Potentially fair – 16° C -22° C
    - Potentially limiting less than 16° C and above 32° C for 8 months
2. Rainfall
    - Potentially optimum – >650 mm distributed evenly over at least 6-8 months
    - Potentially fair – 400 mm-650 mm (distributed over at least 6 months)
    - Potentially limiting – <400 mm within the first 6 months
3. Altitude
    - Potentially optimum – 0-1200 masl
    - Potentially fair – up to 1500 masl
    - Potentially limiting above 1500 masl

[3] Interactive precipitation maps are available on line. One example is http://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=TRMM_3B43M, which covers each month from January 1998-June 2011.

Exploring the suitability of East Africa's general climate

East Africa has complex and increasingly variable rainfall patterns, and while dry periods are predicted to increase, overall precipitation is expected to rise, depending on the models used (Giannini, 2008).

Most of East Africa around Lake Victoria and those coastal regions subject to the Southwestern monsoon, experience bi-modal rainfall patterns.

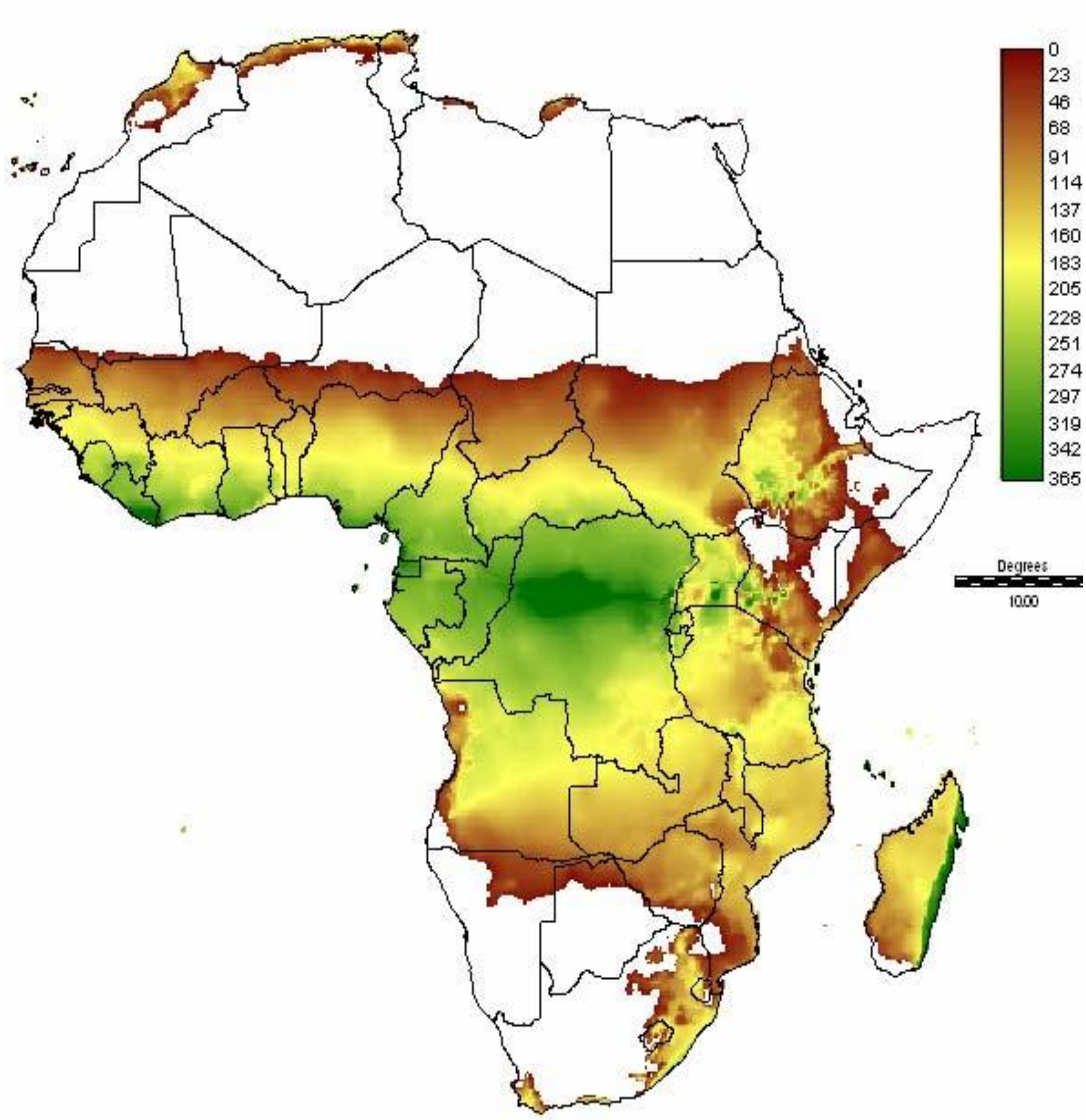


Figure 2. Length of growing periods (days per year) in 2000 in Africa (Thornton et al 2006).

While not proven, field observations indicate that for jatropha to have a chance of becoming commercially viable, well adapted bred varieties need optimal conditions in the first 5-6 months, in terms of temperature, rainfall, nutrients, and good management, so that the plants (for most varieties) can reach above 1 metre in height. Reliable 150-180 day growing periods are scarce in East Africa, and are actually projected to become shorter, making it a challenge to get the timing right for planting jatropha.

With long rains in March/April and short rains either starting earlier in August or later in October/ November, it may initially seem sensible to use the late February/ March planting window. However, the dry and increasingly cold winter that follows at higher altitudes does not support strong jatropha growth. There is also strong evidence that, linked to sea surface temperature changes in the tropical

Pacific Basin (rather than the Indian Ocean), there has been a recent and abrupt decline in the East Africa long rains since 1999 (Lyon and de Witt, 2012). Figure 3 and Table 2 show the failure of the 2009 long rains in Rea Kilifi just as they set out the provenance trials. After some limited rain just after planting in June, the plants had to wait until the October downpour.

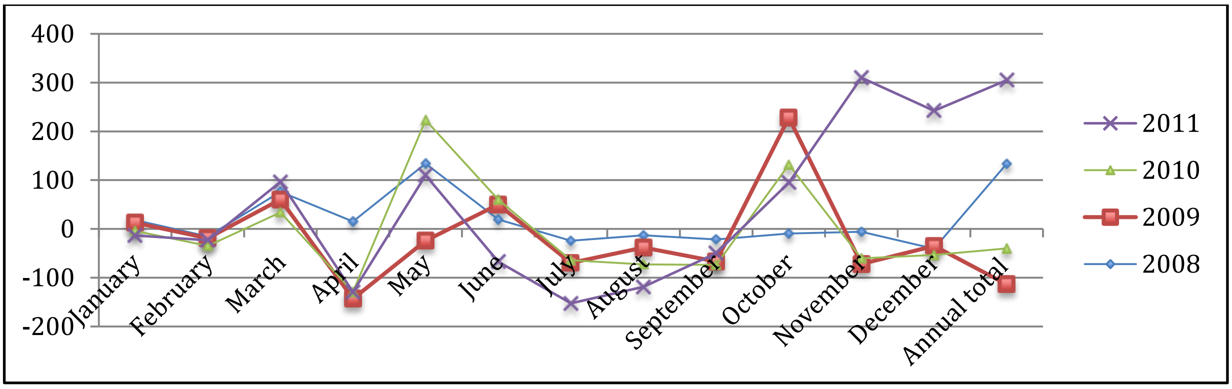


Figure 3. Recent rainfall patterns in mm in Kilifi against 50 year average (plotted as zero on y axis) The red line shows the failure of the April/May/June rains in 2009, and more extreme precipitation events towards the end of the year.

Table 2. Actual rainfall in Kilifi 2008-2011 (mm)

	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual total
08	35.2	0	120.7	218.8	472.3	173.6	86	59	35.5	96.1	83.6	3.7	1384.5
09	12	11.5	28.5	45.7	180	185	65	47	11.7	343.2	23.5	49.9	1003.8
10	0.3	0	18	217.5	585.5	164.5	115.5	37.5	50.1	9.3	101	25.5	1324.7
11	8	27	107	204	225	27	22	26	81	69	460	340	1596.0

Traditionally, the rains start on March 15th. However, the April rains are becoming less reliable. The 'April/May/June' rain events can be more evenly spread than in the more thunderous end-of-year storms. In 2008, researchers in Tanzania showed the connection of East African rainfall to changes in Northern Hemisphere climate. They suggested that the East African rains may be susceptible to sudden changes catalysed by industrialised human-induced climate change in the Northern Hemisphere.

Perhaps, despite historical averages, a jatropha grower in Kenya may now risk second-guessing a favourable El Niño oscillation (e.g., 2009-2010/2011-2012), which could create sufficient intermittent rainfall in December, January and February to maintain a sufficiently long initial growth period in the potentially more optimal hot season temperatures. In this case, a farmer could develop an irrigated nursery in late August/early September, for planting with the short rains in October/November.

Many current jatropha-suitability maps do not reflect seasonal variations. Using the above criteria and based on historical rainfall and temperature averages since 2000, the maps below (Meshak Nyabenge, 2011) illustrate the importance of the first 6-8 months of rainfall for increasing the chances of reasonable commercial success.

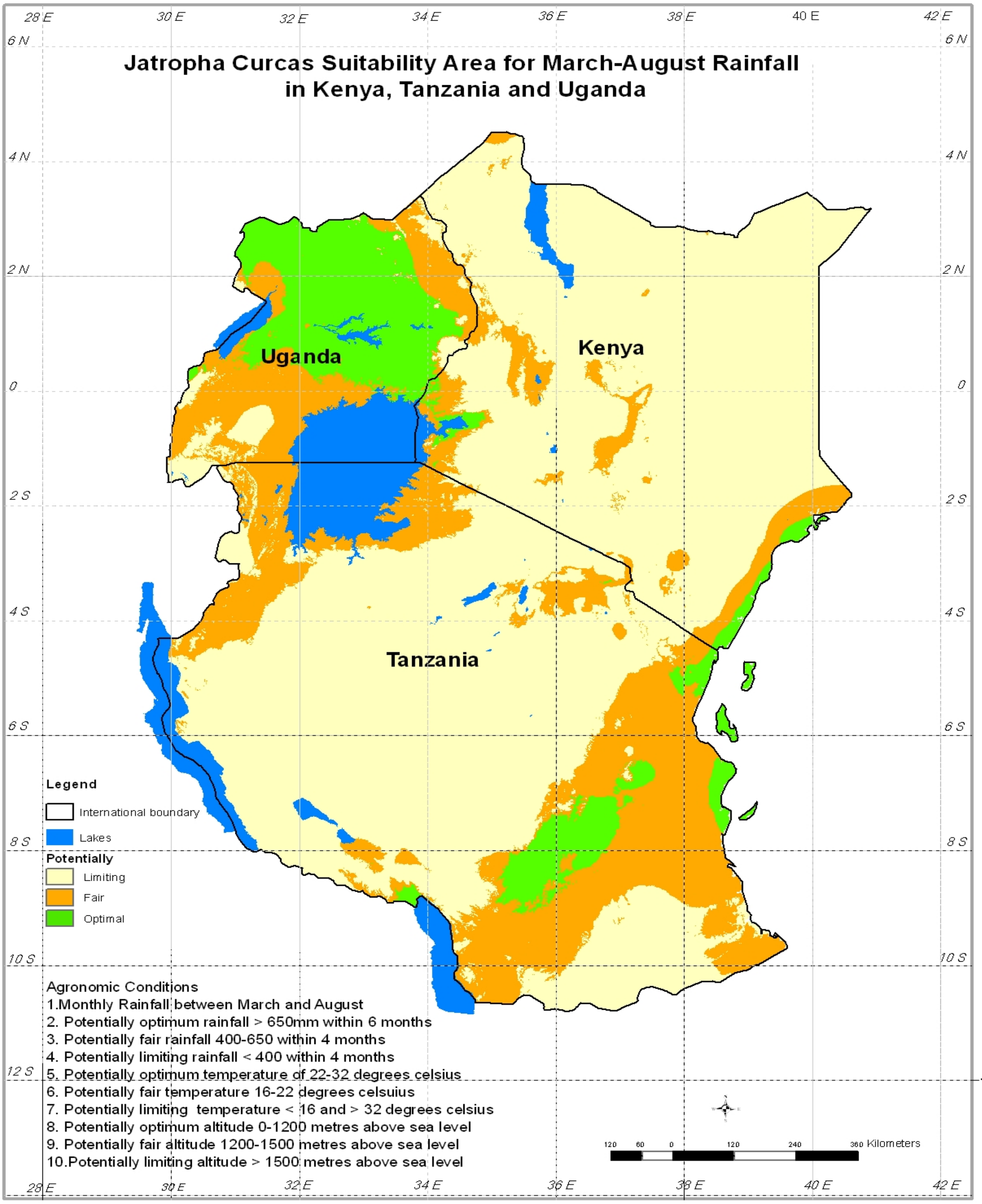


Figure 4: Map of East Africa showing the potential for growing jatropha planting or transplanting in March.

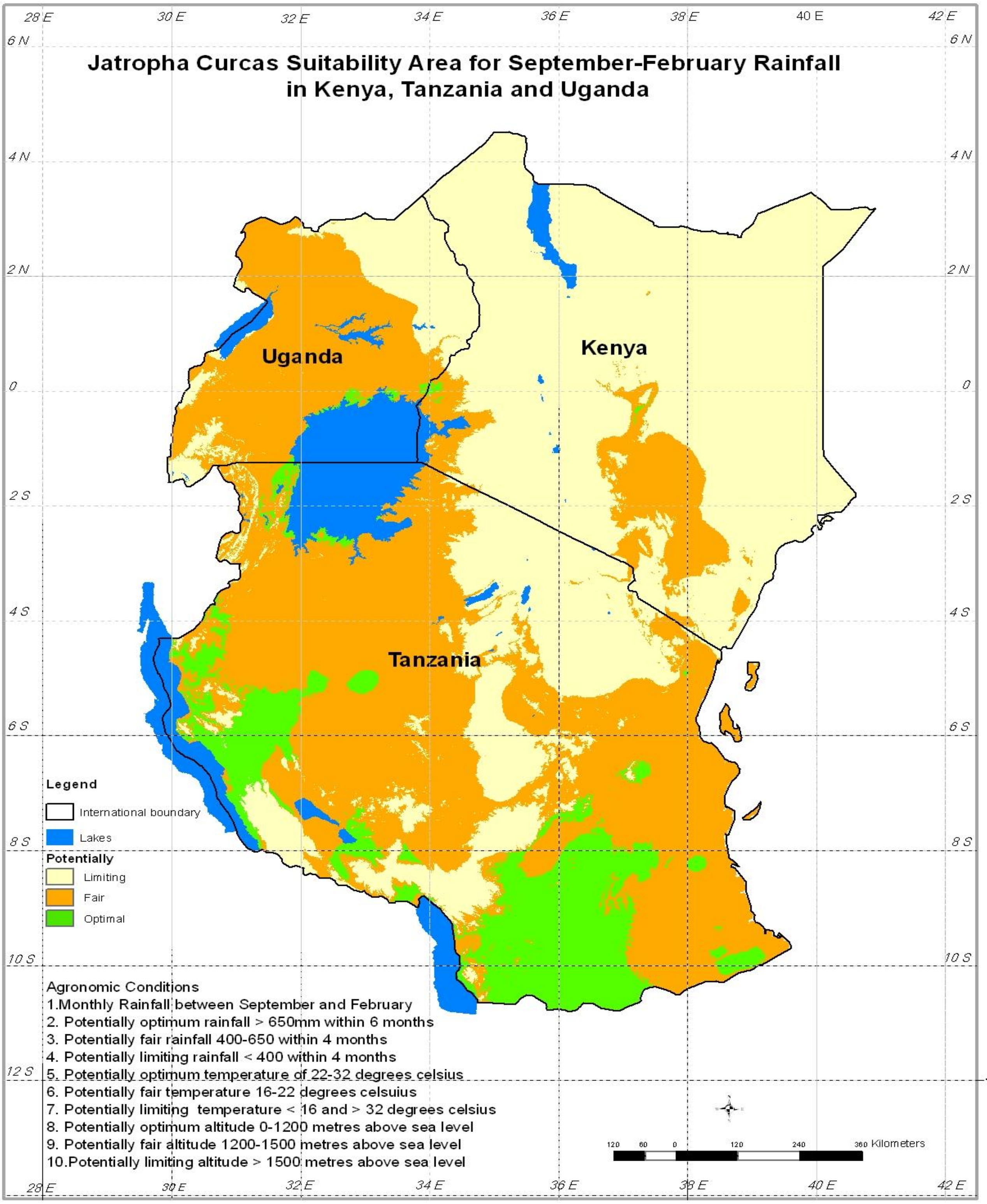


Figure 5. Map of East Africa showing the potential for growing jatropha planting or transplanting in September.

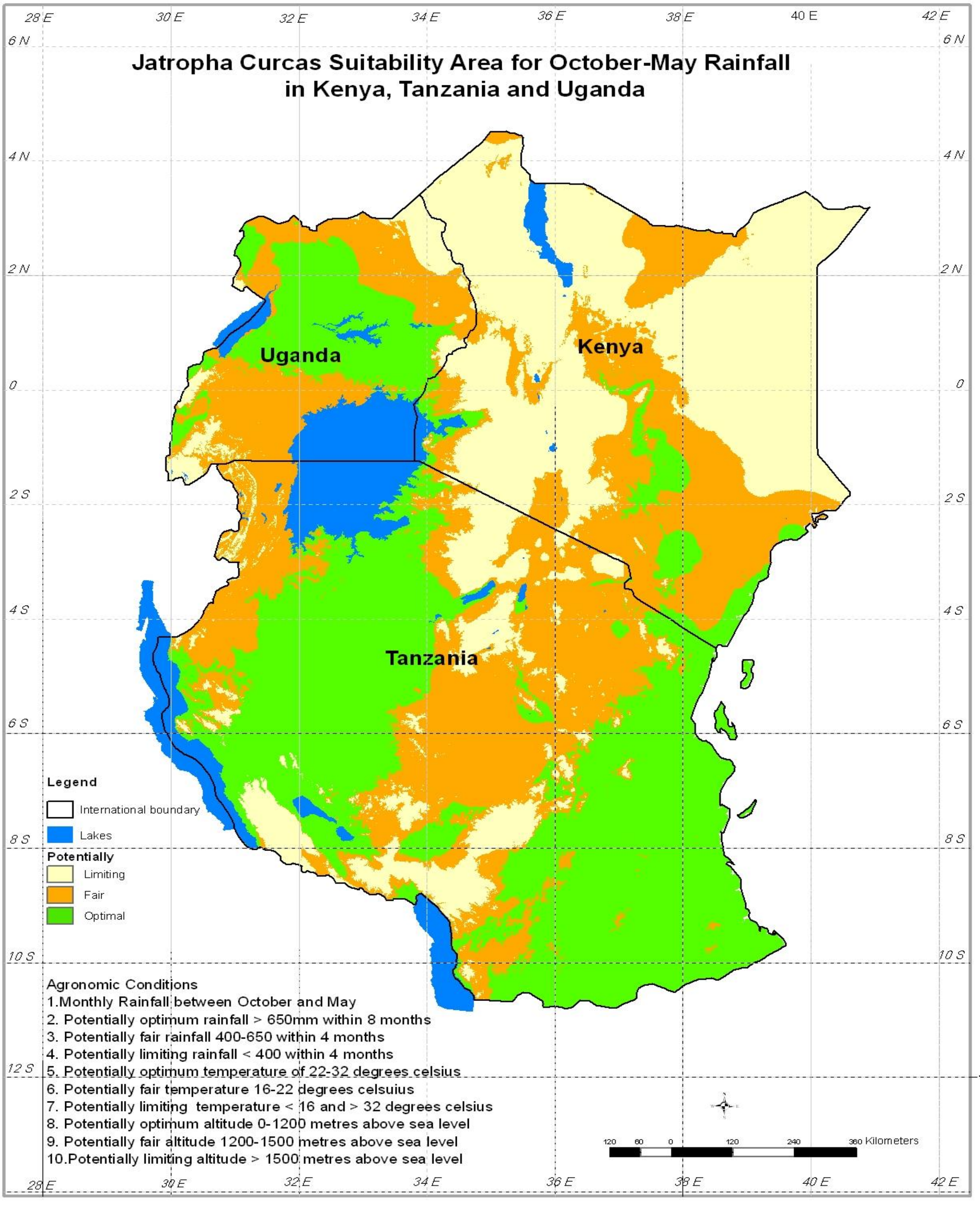


Figure 6. Map of East Africa showing the potential for growing jatropha planting or transplanting in October, assuming rainfall is distributed evenly through to May.

As Figure 4 shows, planting at the beginning of the March long rains leads to potentially limiting conditions (the yellow area) in most areas of Tanzania and Kenya. The orange areas suggest a potentially fair growth, which will increase the need for either supportive irrigation or increased soil and plant management, and so increased costs.

Figure 5 shows the conditions between September-February, on the understanding that when jatropha seeds are treated, they can survive well if they are planted directly prior to the rains so as to take advantage of any early rains for germination. Generic maps are limited in what they can show in terms of actual potential on the ground.

While Figures 4 and 5 illustrate the potentially limiting arid/semi-arid belt that runs from Northern Uganda across North and Northwest Kenya through to Southern Central Tanzania, and the high plateaus and mountains, they demonstrate the potential of the tropical coastal monsoon climates and tropical seasonal inland climates.

Technically (using historical averages) planting at the beginning of the short rains in October, should be even more limiting in Kenya and Tanzania, than at the inception of the long rains starting in March. Nevertheless, our experience showed that while the drought of 2009 proved limiting all over Kenya and Tanzania, the traditionally unseasonal rains that then continued through December/January and February provided a five month window of opportunity in arid areas that was not there for earlier planting in the year. Thus, Figure 6 takes the period between the short rains starting in October through to the end of the long rains in May, as if the rainfall during this period would be distributed evenly. It emphasizes that favourable El Niño oscillation years, where rain continues through December, January, February, could just create an infrequent window of opportunity for early growth and establishment. However, this may result only in fair yields in future long rainy seasons, as well as a limited second season fruiting in future dry oscillations.

What the project observations have also revealed is that the 'margins of error' for setting up a jatropha plantation are very small in the potentially limiting and fair conditions that exist throughout almost all of Kenya and extensively through Northern and Central Tanzania. Small increases in rainfall at the right time can have a dramatically beneficial effect, while small decreases can lead to very unpromising results. While temperatures and traditional rainfall patterns at the Kenyan coast are potentially optimal, the increasingly unpredictable rainfall patterns makes mono-culture large-scale commercial production a high-risk business, especially if commercial sustainability is dependent on repaying initial loans within a certain set-up timeframe.

It is worth comparing our minimally selected figures with others' observations and extrapolations of climatic growing conditions for *Jatropha* curcas in Africa (e.g., Maes, et al., 2009). There is very little widespread first hand evidence.

Table 3. Adapted from Maes, et al. (2009)

	Minimum temperature	**Maximum temperature**	**Precipitation mm per year**	**Length of growing season months**	**Length of dry period months**
Optimal range	14.4 – 19.4	31.5 – 34.0	1207 - 2001	6-9	0-4
Total range	10.5 – 21.2	27.4 – 35.7	944 - 3121	5 - 11	0-5

As indicated in our original table of sites, the areas that remain potentially limiting – whatever planting start date you choose – tend to be too dry and/or have too many days and/or nights at less than 15^0 C, usually due to altitude and/or local conditions. With favourable water-retaining soils, jatropha can grow slowly in dry conditions, however it will not be commercially viable without proper water and nutrition management. In Kenya, even though Nakuru is at a higher altitude (~2000m.a.s.l.), Thika and Naivasha have a higher number of colder nights, which limits jatropha growth.

Describing optimal rainfall and temperature conditions

While yields depend on many things, Trabucco, et al. (2010) again used climate-aggregated data to take an ecological perspective on optimal jatropha yields. They suggest that tropical climates with mean minimum temperatures above 18⁰C or monsoonal climates with distinct dry seasons are potentially optimal. They suggest that the difference between night and day temperatures should not exceed 10⁰C, with an average temperature of 27⁰C and maximum temperatures of not more than 35⁰C. They suggest that outside the tropics, potentially optimal conditions are found in warm temperate climates with no frost risk, characterized by either having dry seasons or being fully humid. Other climates, such as tropical zones with no dry seasons and subtropical deserts are considered to have moderate yield potential.

Regarding annual rainfall figures, despite the original hype based on the ability of the plant to avoid drought, it is increasingly accepted that, while jatropha can grow well if it receives 1000mm, rainfall distribution is also important. This allows for an optimal wet season of over 800mm, as well as a dry season of less than 200mm of rain, with enough rainfall in between to maintain steady growth. Whatever the omissions or projections in their modelling (Trabucco, et al., 2010), the emphasis is on jatropha doing well under reliably seasonal conditions, especially in terms of a dry season and to some extent a cooler season, and they support the conclusions of Maes, et al. (2009) that arid and semiarid conditions are potentially limiting for jatropha. Distinct seasonality also focuses the flowering and fruiting into more discrete patterns.

Microclimates and rain shadows

The many East African microclimates and rain shadows are not captured on large-scale maps. More specific local conditions can create patches of more or less favourable conditions. Table 4 shows accurate rainfall data taken from two individual sites and the combination of four sites, all within 16km from each other around Lake Naivasha. Figure 7 shows the annual variations at Point 1.

Table 4. Accurate average rainfall per month at different points around Lake Naivasha Rift valley Kenya, not more than 20 km apart

2010 monthly averages mm	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Sum
Point 1. The average of 4 on farm Vegpro sites including office and pivot c	79	96	99	66	114	17	26	26	85	90	41	30	768
Point 2. 4km from pivot c 2 km from office		107	106	51	105	12	18	5	29	62	13	17	525 -jan
Point 3. Oserian 16 km away	64	113	142	91	158	26	14	30	121	78	64	12	911

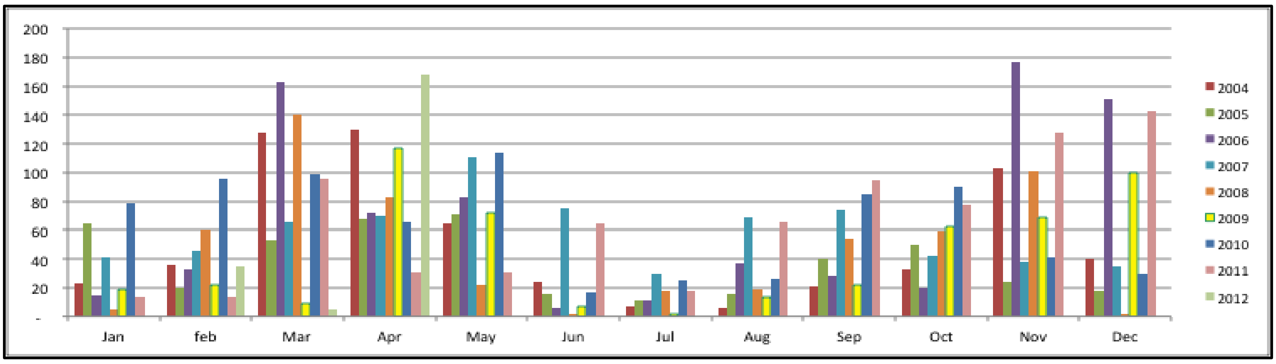


Figure 7: The variations in average monthly rainfall in millimetres over an 8 year period at point 1 in Table 4.

Table 4 and Figure 7 demonstrate the very different rainfall patterns within a 16 km radius around Naivasha and the variability of rainfall patterns from year to year, respectively. So, for instance, jatropha planted in February 2004, from a rainfall perspective, could have grown to a reasonable height and size, but if it were planted in February 2005, it would have failed. As emphasized above, the truth that underlies the regional generic maps based on historical averages is that commercial success is wholly dependent on actual supportive patterns of rainfall and temperatures once you plant either seeds or seedlings. The increasingly unpredictable weather patterns in Kenya and Tanzania may also be, in part, responsible for the conflicting reports of varying jatropha success or failure. Some retrospective assessments do not ask farmers the exact rainfall or temperature patterns immediately following planting, but rely on historical annual precipitation and temperature averages. Establishing jatropha successfully depends on how the rainfall is distributed after planting.

In summary, the general mapping of East Africa's average climates suggests that even with good management practices, soil nutrition and optimal temperatures, increasingly unpredictable rainfall patterns could limit growth and productivity. Unpredictable rainfall patterns mean that most fair and potentially optimal areas in Kenya and Northern Tanzania can be reasonably described as risky areas for solely rain-fed jatropha during the establishment phase. The risk is lower in parts of Uganda and Tanzania. Among our trials, Masindi in Uganda seemed to have sustained potentially optimal conditions (wetter and warmer) thanks to the Kenyan and Tanzanian coastal monsoons providing good temperatures, a dry season and often overall adequate rainfall per annum.

After correct rainfall patterns and optimal temperatures, genetic and adaptive realities, site-specific soil structure and nutrients, set-up design, the prevalence of pests and diseases, and the management practices used all influence final yields. Each site demands a sequence of production set-up activities and decisions that are critical to possible commercial success. In this report, we share the insights and observations we can to assist and inform investors' decisions.

Section Two: The more detailed results of commercial feasibility trials

The purpose of this section is to respond to the detailed aim within the project to look at the impact of soil characteristics, rainfall and temperatures and to make some preliminary observations about intensity of cultivation. A more detailed description of each site is given separately.

Seeds

Nineteen provenances were collected from across East Africa. BioGreen Technologies collected the seed in East Africa from known high-performing wild trees. DI Oils sent three varieties from Madagascar. First impressions suggested that the seeds carry some adaptability to the agro-climatic conditions in which they matured. Because they came from agro-ecologically very different sites, the same provenances performed differently in different locations. Variances in germination, plant height, and plant architecture and branching reflected jatropha's high environmental sensitivity.

While most jatropha fruits have three seeds, the picture above shows fruit with 2, 3, and 4 seeds from fruits on the same tree. This may not make much difference to seed weight and oil content. What the project demonstrated, however, is that the same batch of wild seed can yield very different growth patterns under the same agro-climatic conditions. However large or small the genetic proportion of jatropha's response to different environments, looking for some kind of genetic uniformity through true-to-type breeding programmes is perhaps a first step towards increasing the reliability of commercial scale yields.

For planting purposes, it is worth ensuring that most of the seeds are fresh and large, and selecting for propagation is worthwhile, especially in direct planting (Zaidman, et al., 2010). They should be dried to a moisture content of less than 6% for long-term storage. While seeds are generally considered to be better quality when dried in the shade, there is scant evidence that drying yellow fruit in the sunlight for three days affects germination, oil quality, or the Free Fatty Acid (FFA) content of the oil.

Germination

When the seeds were first given to the companies involved in this project, a germination protocol of soaking the seeds in water and manure was recommended. Each company soon adopted different soaking protocols and direct seeding in different types of seedbeds and/or poly bags. Different companies chose different approaches, some creating seedbeds under sophisticated shade netting, some choosing poly bags, and some, such as Rea Vipingo located in the warmer climate of the coastal zone, planting directly into sand-based seed beds.

Figure 8. Germinating the seed in Kofinaf, Rea Vipingo poly bags and Masindi direct seeding.

In the rift valley and central Kenya locations, it soon became clear that maintaining a temperature of over 27^0 C was crucial to germination; thus many plantings were covered in polythene to maintain higher temperatures at night, as well as humidity.

Figure 9. Nursery germination regimes to maintain night temperatures at Kofinaf, Thika and Saffron Laikipia, 2009.

As seen in Figure 10 below, these factors led to different germination rates of different provenances in the different locations.

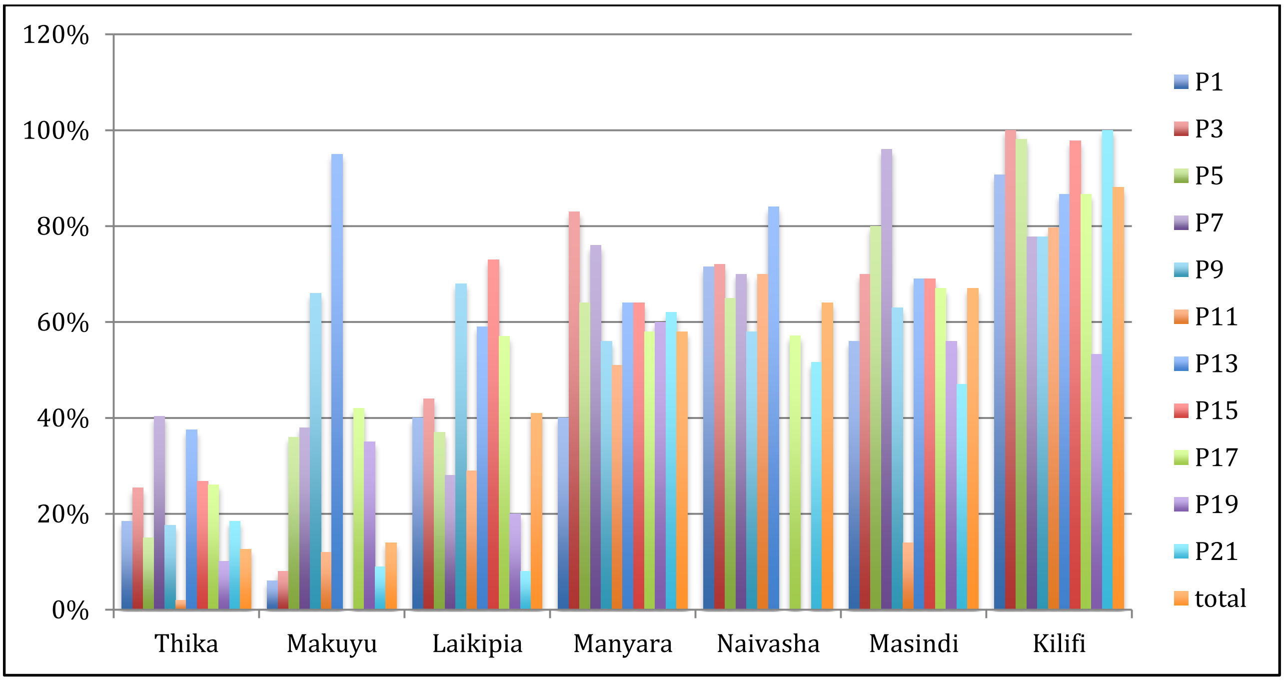


Figure 10. Percentage germination data of selected jatropha seeds at six different sites with different climatic conditions.

A full 'percentage germination' table is in Annex Four, along with a full set of 'nursery notes'. Germination was close to 100% under warm, humid conditions at low altitudes (e.g., Kilifi) when freshly harvested seeds were used, and below 50% in areas were the average temperatures were lower (e.g., Thika). Even at sites at higher altitudes the germination was higher than 50% when the average temperatures were maintained by using plastic or other methods to keep the seeds warm, such as digging trenches and filling with compost mixed soil (e.g., Mbeya).

The findings support others in saying optimal germination is between 27-30^0 C (Kaushik, 2003). Even with mitigation techniques, this heat is hard to maintain under fair and limiting temperature conditions, except in specific seasons. A further challenge for growers is that the warmer locations also tend to be the drier ones. Over most of the sites, exactly the same seed was distributed, with a top up of some collected provenances from the same wild trees in the next season for those starting later (e.g., Mbeya). The results shown in Annex Four demonstrate that germination rates were highly dependent on the conditions under which germination was attempted.

The challenge in East Africa is that for optimal larger-scale germination of any direct field planting, the warmer months precede the increasingly unpredictable long rains, and the months before the shorter August-October/November rains are cooler. While NGOs may sell ‘selected’ seed for up to US$17 per kg, the cost of selected and ‘reliable’ seed from international breeding companies can be around US$15-20 per kg (Volkaert, pers. comm., May 2012). One kilogram of seed is sufficient to cover one hectare with 2 seeds per ‘station’. The issue for large-scale plantings is the availability of enough reliable seed for the short planting window, such as those encountered in mono-modal systems.

Testing different germination protocols under laboratory conditions found that scarification and constant temperatures above 27-30^0 C had a much greater positive impact on germination than soaking. Common wisdom says soak the seed for at least 12 hours (e.g., Ouattara, et al., 2011). However, in some cases the seeds rotted and in others it did not seem to make any difference. Lab tests showed that scarification of the pericarp (drilling, cracking or grating) led to 80% germination compared to 32% with seed that was not scarified. However scarification is not suitable for pre-planting seeds for direct seeding prior to the rains, nor for commercial tonnages of seed. It can be useful for specific breeding programmes, small amounts of specialist seed or smallholder farmers. One company found that just planting the kernel yielded 100% germination. There was also some thought that planting seeds horizontally leads to a better chance of the sticky pericarp remaining in the ground and not damaging the first two cotyledon leaves.

If fresh seeds are sown during seasons where ambient temperature are high and soil moisture can be maintained, direct sowing can be adopted. The soils in such cases need to be deep, loose and fertile. In such cases, 2-3 seeds may be sown per pit so that robust seedlings can be retained and the others removed in due time.

For all the above reasons, except cost, it is probably wise to grow seedlings in a nursery first and then transplant them to the field. The nursery protects the seedlings during the initial tender phase. It allows for better care and protection, including from pests and pathogens during this phase, assures higher survival rates and the choice of the more robust seedlings capable of establishing in the field once transplanted. It may be best to move the seedlings directly from raised beds to the field and not into poly bags, which are often too small. One study recommended river sand and 5x10 cm poly bags (Geply, et al., 2011), while another found seedlings grow best in sandy-loam and clay-loam soils rather than sandy soil (Valdes-Rodriguez, et al., 2011). Sometimes the seedlings are re-potted too deeply, leading to significant losses from base stem root rot if over watered (Anderson, 2009, personal experience).

Because of immediate water storage in their stems, jatropha seedlings in poly bags can resist drought, although their initial growth can be arrested, as demonstrated in the test nurseries. Poly bags need to be large enough to ensure that the taproots do not turn and become curled (‘J’ roots). Using stressed initial planting stock is perhaps one of the less-highlighted contributing factors for the overall disappointing performance of smallholder-based jatropha pilots (GTZ, 2010). As long as seedlings have adequate space in seedbeds or larger poly bags they will develop full lateral roots and a straight taproot. They need to be planted out in a timely manner to allow the growth process to continue uninterrupted.

The breeding, genetic modification, internal seed structure, germination processes and responses of jatropha seed under different conditions are now being studied quite intensively (e.g., Mohan, et al., 2011; Islam, A., et al., 2011; Sujatha, et al., 2008; Misra and Misra, 201; Basha, et al., 2009; Attaya, et al., 2012).

Oil Content

Dr. Jacob Kithinji of the University of Nairobi chemistry department did the oil analysis work for the project. The percentage oil results were highly varied and so no particular conclusions can be drawn at this point[4]. Others have reported oil content ranging from 24-44% (Ovanda-Medina, et al., 2011) and 8-54% (Khetri), while still others have observed that that the oil content differed considerably from the same trees between two sequential fruiting seasons (Kaur, et al., 2011).

Researchers have reported that both the content of oil, as well as the proportion of fatty acids, are highly inheritable and that oil content was negatively correlated with altitude. The higher the altitude, the lower the oil content and the higher the proportion of unsaturated fatty acids (Ovanda-Medina, et al., 2011). Given that East Africa has many potentially fair to good production zones at higher altitudes, this is a measure that needs further investigation. The region also tends to be both wetter and colder, and have comparatively more cloudy days and lower (or higher) humidity, factors that also require further study. Overall, in our small sample the variance was too wide to determine any consistent patterns.

Agronomists on the project noticed that the same plants produced different seed sizes and weights in different years. This apparent annual variance needs to be more fully understood, especially as it relates to sustained commercial success. The most likely factors are rainfall, temperature, sunlight patterns and micronutrient availability during flowering, fruiting and harvest periods. However, overall the current wisdom seems to be that given there may be some inherited traits for oil content and composition, agro-climatic conditions will play a major part in final oil yield and composition (e.g., Belewu, et al., 2010; Volkaert, 2009). Attempts within the experimental design to test the influence on oil content of applying micronutrients were unsuccessful due to the lack of significant early variance in poor-performing trials and the lack of enough time for all plants to come to fruiting under adverse conditions.

Variations in growth patterns between the provenances and the different sites

Jatropha curcas is known as a plant with a very high degree of phenological plasticity, as well as great sensitivity to environmental conditions. A recent study estimated the heritability of seed yield and vegetative traits at between 0-23%, with plant height being one noticeable aspect. Otherwise, environmental factors seem to play a larger part (Rafii, M. Y., et al., 2012). The results of this DEGJSP study also indicate that a multitude of environmental issues and management practices play a large role. In some circumstances, for example, better soil and rainfall conditions may mitigate the impact of lower temperatures. There may be a whole series of these mitigating interactions yet to be determined.

The impact of drought at the start of the project

The project began in November 2008. The seeds were collected and distributed as quickly as possible, and the nurseries in Rea Kilifi, Naivasha, Laikipia and Makuyu were established in February/March, expecting to catch the April/May rains. However, especially in Kenya, drought prevailed from April 2009 through to the 2010 long rains. This prevented some companies from laying out the trials, some seedlings stayed too long in poly bags, and for those that went ahead, such as in Makuyu and Kilifi, the initial growth was stunted. Material planted out under limited rainfall, as well as that which stayed in the nursery too long did not perform well.

[4] Table of results available in Annex Five

Table 5. Nursery set up and planting out times across all the sites

	Kilifi	Laikipia	Naivasha	TFM Makuyu	Masindi	Nakuru	Manyara	Bungoma	Mbeya
Nursery set up 2009	13/02	03/03	05/03	22/03	23/07	28/04	05/06	24/07	01/10
Planting out dates	22/05/09	12/11/09	16/01/10	28/04/09	03/10/09	18/08/09	20/12/09	22/09/09	19/03/10
Days in Nursery	98	254	(314)[5]	37	72	112	198	60	169

Table 5 shows the protracted times that the plants stayed in some nurseries, sometimes beyond the 45-60 day guidelines provided. In Naivasha, the nursery had to be set again later in the year. In Laikipia, gap filling was done with direct seeding; because the rains had come, these plants performed slightly better than those from the nursery. An older small plantation in Kilifi, located on a previous cattle boma, had grown well in rains the previous year and the plants were already over one metre tall when the rains failed. They went into dormancy and suffered little damage. These experiences on the project emphasize the challenge of finding the optimal timing and planting season in the context of some of the more erratic East African weather patterns.

Climatic variability did result in different average growth patterns across provenances and between sites. The figures below show some comparative results of the plant heights reached at different points during the project.

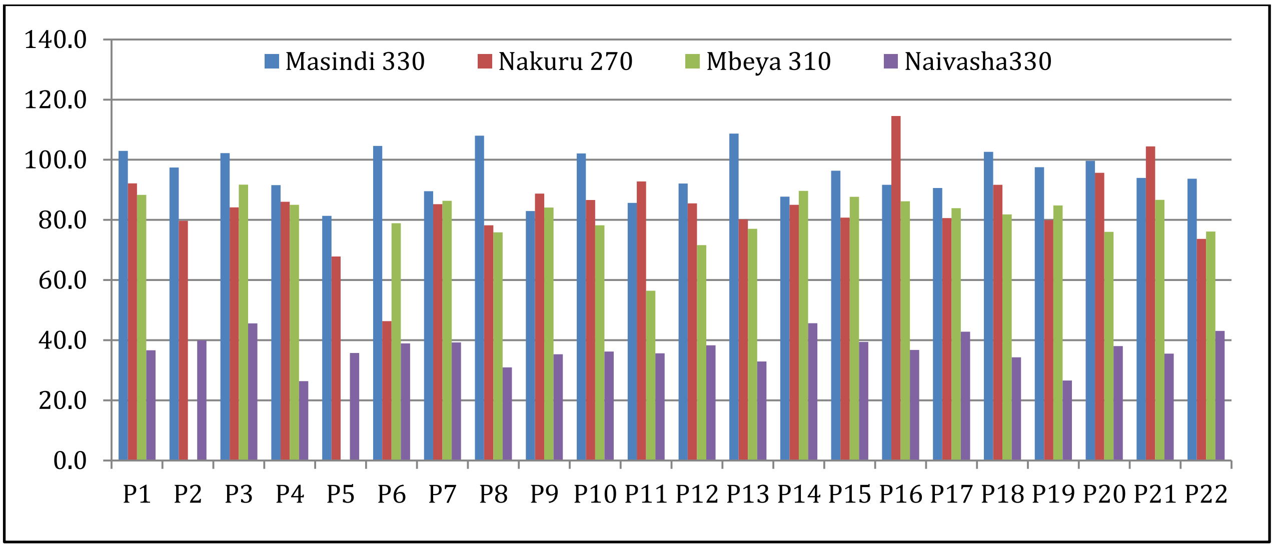


Figure 11. The averge height in cms of the provenances after 330, 270, 310, and 330 days in Masindi, Nakuru, Mbeya, Naivasha respectively

[5] This figure is in brackets as the nursery was set again.

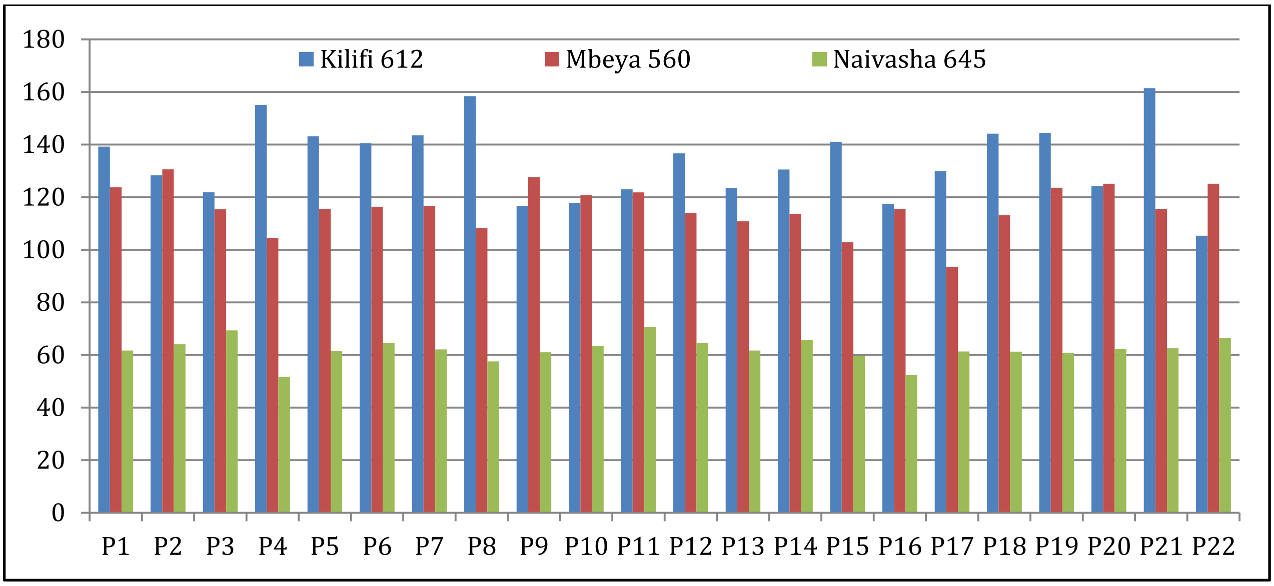


Figure 12. Average height in cms of each provenance after 612, 560, and 645 days after planting out in Kilifi, Mbeya and Naivasha respectively

Figures 11 and 12[6] show the average of mostly 15 plants per provenance spread over 5 replicative blocks. By illustrating the average for each provenance, the figures do not show that, despite a certain amount of selection of seedlings in the nurseries, there was great variation also seen between individual plants in the same plot. This again emphasizes the need for true-to-type breeding and the high risks of using wild seeds in directly seeding large commercial plots.

What Figures 11 and 12 do demonstrate is that different provenances showed differences in growth performance within and across sites. Different provenances did well and poorly on different sites, although some, such as P22, which had undergone some pre-selection, did well on quite a few sites. There also seemed to be some preliminary indication that provenances originating from high altitude regions, such as P11 (origin 1400 masl) and P16 (1300 masl) performed relatively better in high altitude regions, and those originating at lower altitudes did better at lower altitudes (and worse at higher altitudes). However, with so many factors coming into play this relationship has not been demonstrated definitively across all sites. What the growth charts also indicate is that provenances that started off slower in a given location tended to remain slower (and vice versa).

[6] Meteorological data over the project period for the sites illustrated is shown in Figures 16-19 below.

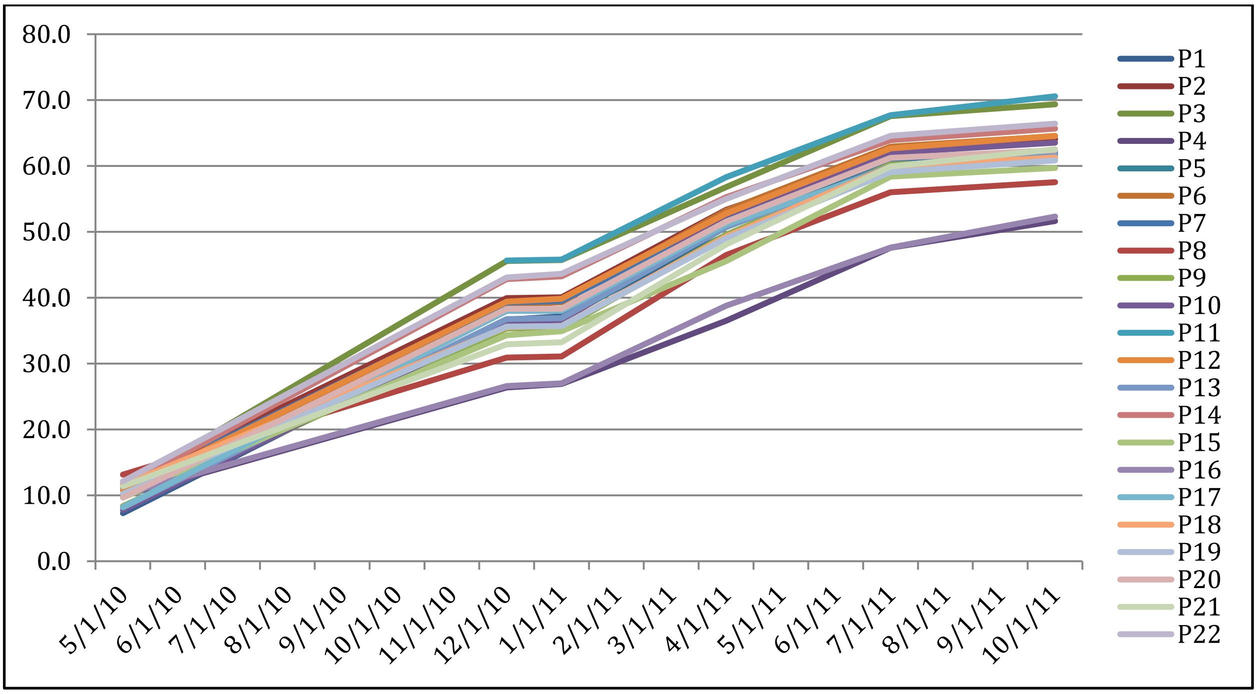


Figure 13. Height in cms of provenances growing in Naivasha between May 5, 2010-May 5, 2011

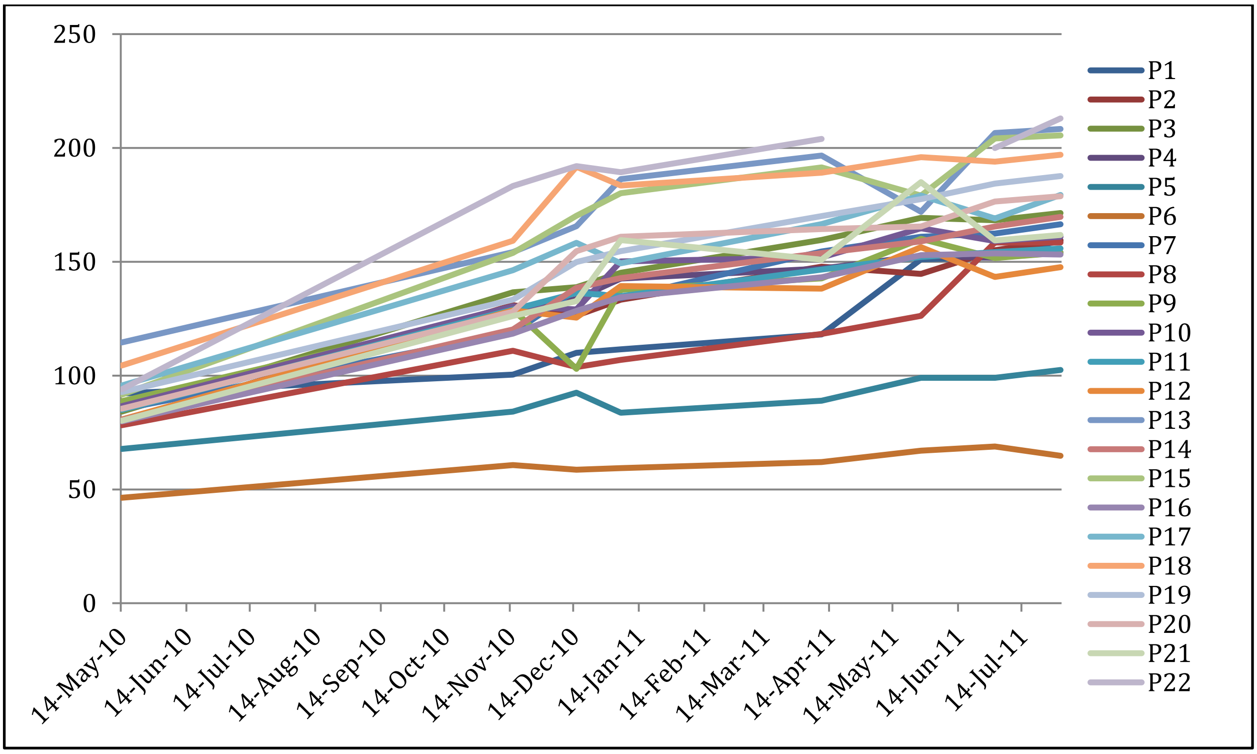


Figure 14. Height in cms of provenances growing in Nakuru between May 14, 2010 and August 1, 2011

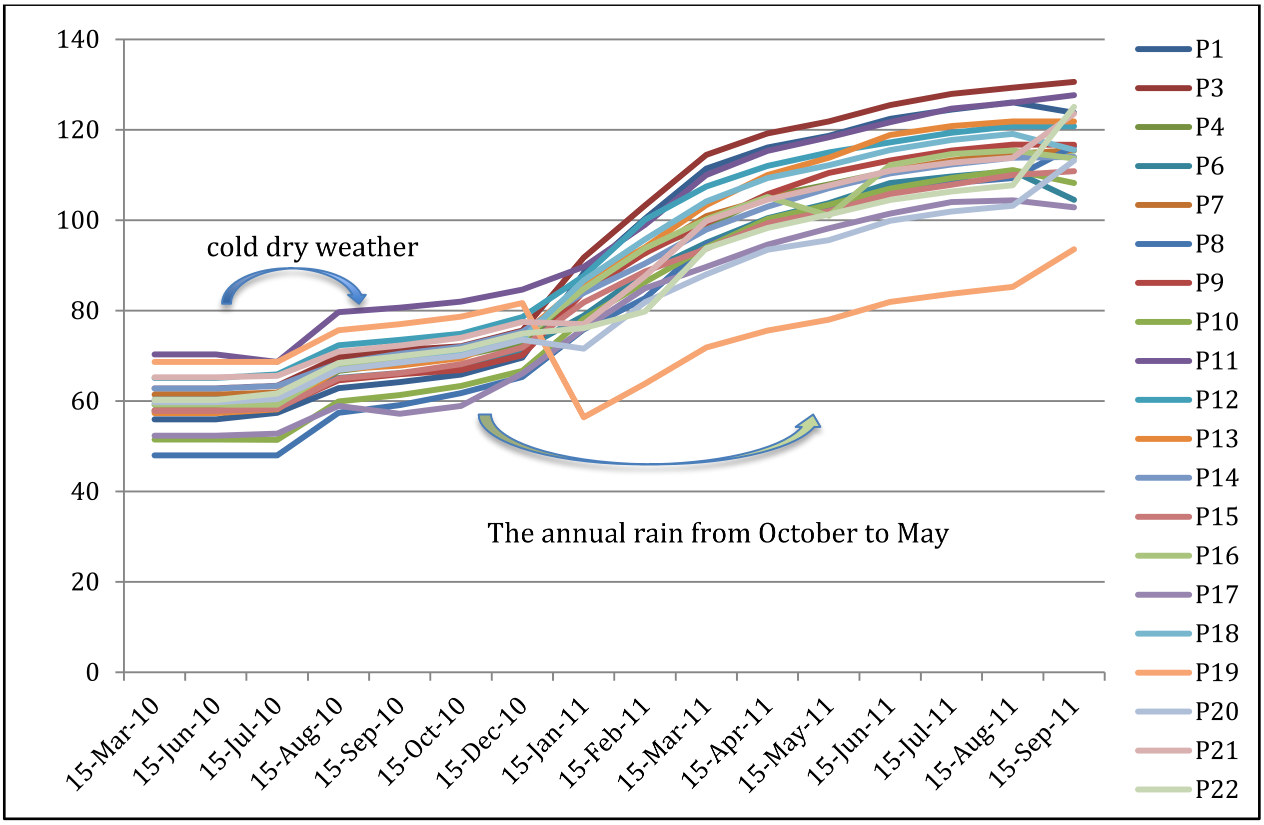


Figure 15. Growth in cms of provenances in Mbeya between March 15, 2010 and September 9, 2011

The Nakuru chart (Figure 14) shows the challenge of measuring the same plants consistently over time, particularly between full leaf and leaf-shedding times. Nevertheless, while a few plants apparently showed improvement, the provenances that started off poorly tended to remain poor. Whatever jatropha's environmental sensitivities, the plant does need a smooth strong initial growth pattern for commercial establishment. This is a real challenge for commercial plantations. If the rain is inadequate during the first planting to bring the plant above one metre, it is an expensive and difficult decision to clear the field and restart in the next season, a whole year apart in mono-modal systems. It is also highly risky to wait and see if the plants recover and grow to optimal size in the next season or two. The longer you wait to see whether the plants remain suboptimal, the further the original set-up and development plan is delayed and the set-up costs are extended and increased. The following charts show the meteorological conditions for the growth charts above.

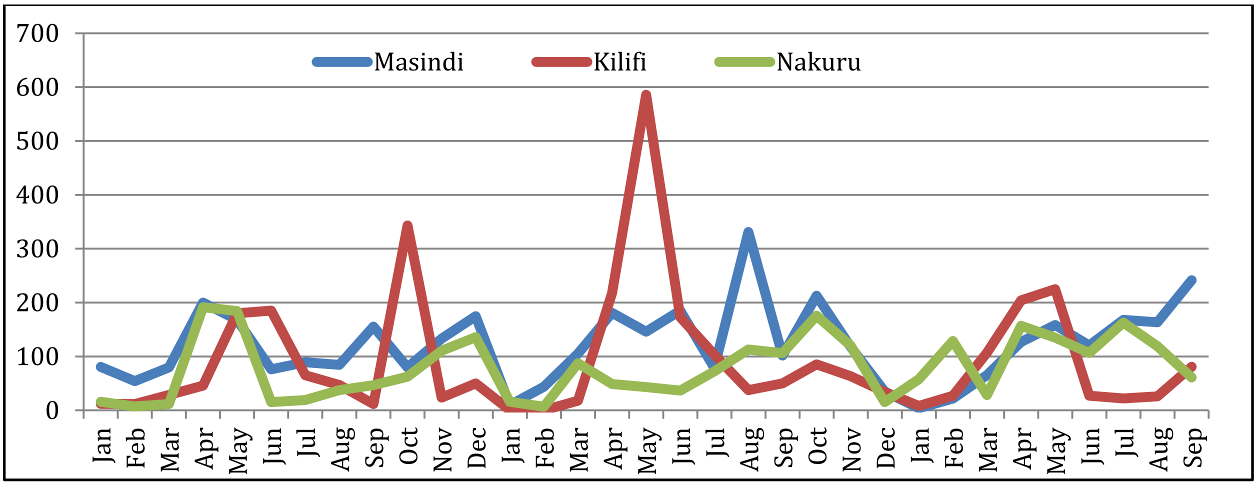


Figure 16. Average monthly rainfall in mms for Masindi, Kilifi and Nakuru, January 2009-September 2011

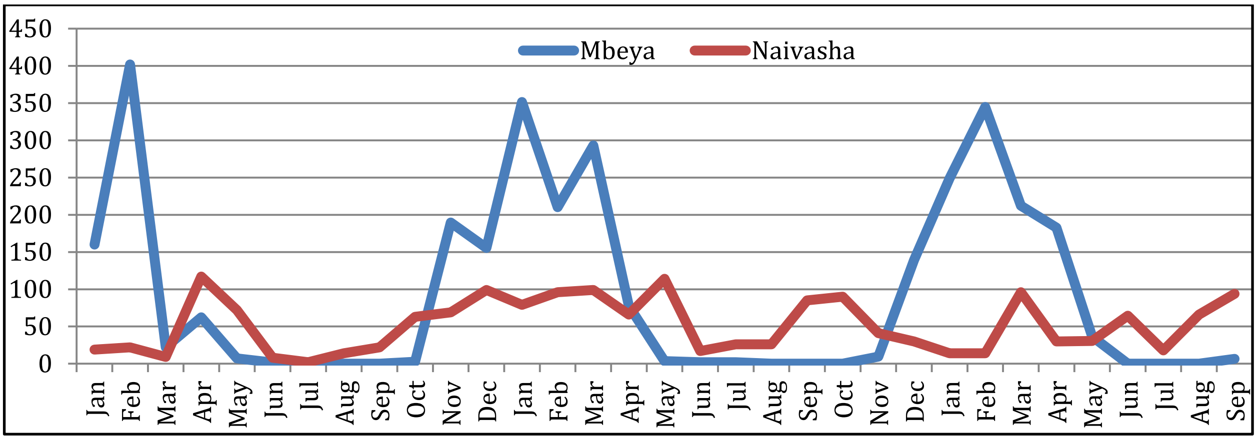


Figure 17. Average monthly rainfall in mms for Mbeya and Naivasha January 2009-December 2011

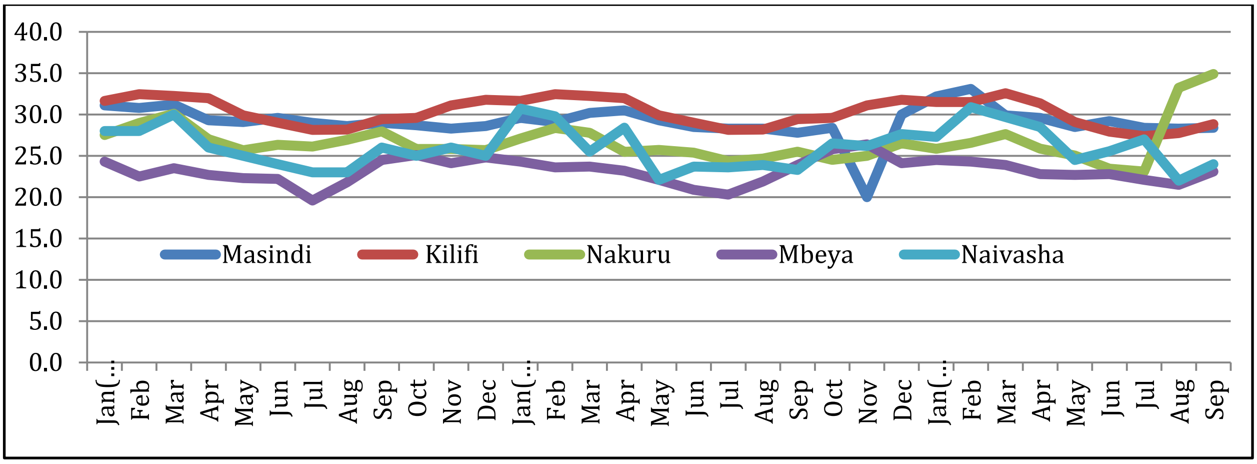


Figure 18. Average Monthly Maximum temperatures in ^{0}C for Masindi, Kilifi, Nakuru, Mbeya and Naivasha. January 2009 – September 2011

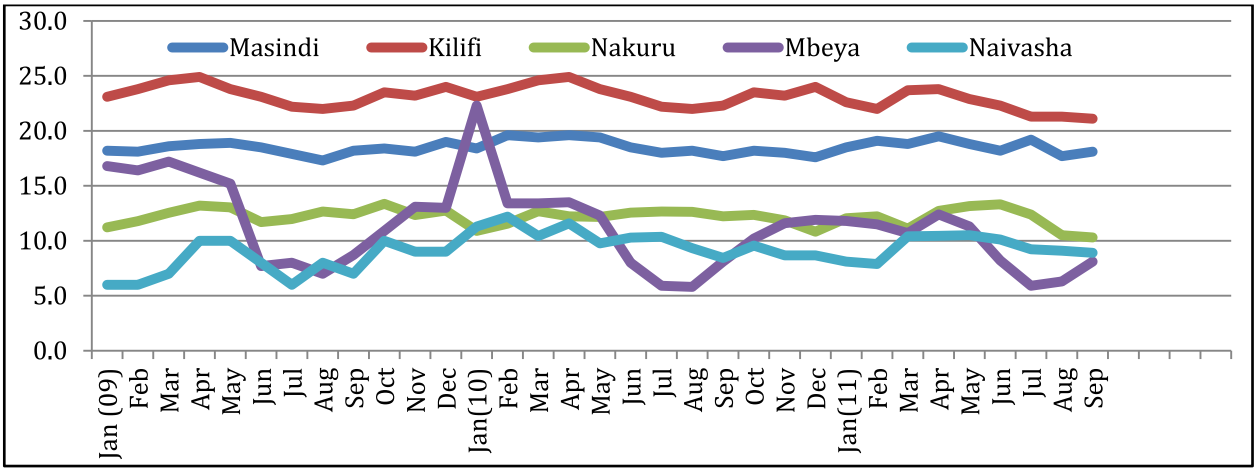


Figure 19. Average monthly minimum temperatures in ^{0}C for Masindi, Kilifi, Nakuru, Mbeya and Naivasha, January 2009 – September 2011

The growth of the provenances was affected by the local climate, as illustrated by the height development of the plants growing in different regions with very different climates (Figures 11 and 12).

Kilifi and Masindi were the two sites that experienced early flowering and fruiting, making them potentially the more optimum sites in the study for growing jatropha. During an October 2011 site visit, anecdotal evidence suggested that the plants in Masindi had grown to 1.8-2 metres high. However, they had few branches and tended to be tall and thin, probably due to lack of management and pruning. The lack of a distinct dry season may turn out to be a limiting factor in Masindi. In Kilifi, while the plants initially grew quite fast, few reached over 1.8 metres by the end of the project. This could have been due to the dry conditions in which they started, as well as the lack of adequate weeding and nutrition. The site was on a seaward exposed slope, which could have reduced humidity and increased wind exposure, unlike the previously planted and more sheltered cattle boma. Kilifi also experiences two dry periods per year and sudden, rather than evenly distributed, heavy rainfall. This pattern may not suit jatropha as well as a strong mono-modal rain system.

The fact that minimum temperatures in Nakuru, Mbeya and Naivasha dip below 15° C for many months of the year, as compared to Kilifi and Masindi, is a significant factor affecting growth of jatropha at these sites. Nevertheless, it seems that in Nakuru there may have be a microclimate created by being close to very large silver grain storage tanks, so that at least the day and evening temperatures may have been higher than shown by the data from the (in this case) government meteorological station.

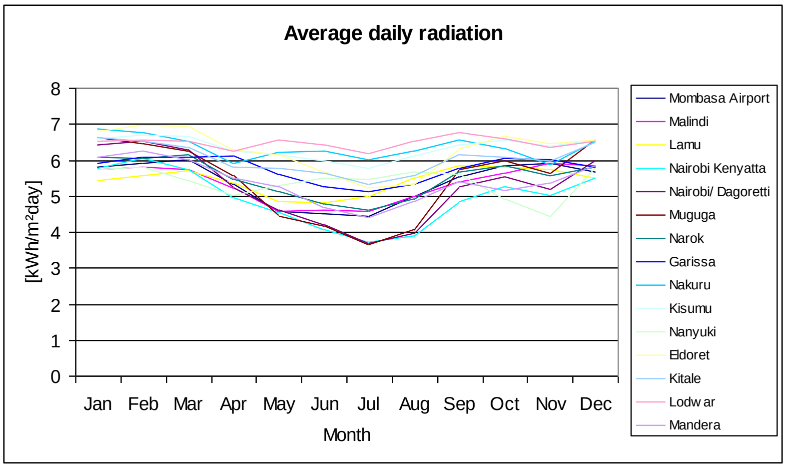


Figure 20. Average daily radiation measured at 15 meterological stations around Kenya by month of the year in the period 1964-1993 (DECON/REAC 2008)

What Figure 20 also seems to show is that Nakuru has the second highest average radiation in Kenya, especially through the June/July/August cold months, and Jatropha is known to increase its photosynthetic capacity with increasing irradiance levels and so responds positively to higher levels of sunlight (Baumgart 2007). This, combined with the low but steady rainfall, allowed the jatropha to grow quite tall, even if the bushes had few branches and produced limited seeds. In the original 5-year old plantation, one tree produced 327 fruits after heavy rain, about 0.6 kg, while most produced much less in drier years.

In Mbeya, despite one or two freezing nights of almost 3^0 C in June/July 2010 (which killed all 7,000 seedlings in the economic trials), the plants in the provenances trials had been protected by having been set out three months earlier in rich peat-like soil in a sheltered yet open location. The morning air in Mbeya has 80-90% relative humidity all year around, dropping to between 50-70% towards evening. So, despite very unfavourable minimal temperatures, the 6-month rainy season of between 1100-1300 mm, combined with good soils, perhaps allowed jatropha to at least grow during the rains and use stored nutrients while it hibernates during the dry periods. Despite the higher maximum day temperatures in Naivasha and similar minimum patterns, Figure 12 shows that the adequate rainy season and good soils allowed the plants in Mbeya to grow almost twice as much as in Naivasha and to be almost as tall as those in more favourable sites. Even so, without the higher day temperatures, it is unlikely to be commercially productive as far as seed yield is concerned (limited flowering was reported).

In contrast, the conditions in Naivasha remained too cold and too dry for the plant to grow. This was anticipated and so the economic trials were set in Kibwezi, where they suffered from weeds and poor rainfall. Later irrigated trials in Kibwezi fared much better and exhibited early flowering and fruiting under the warmer temperatures.

In summary, even though the trial plantations were only beginning to produce seeds, it does seem from observations made to date that different accessions have different growth potentials in different environments. As expected, seeds from mother plants that are adapted to certain climatic conditions performed well under similar climatic conditions. It is important for any potential jatropha farmer to carefully select jatropha seed stock, especially since standard seeds are not yet commercially available. It is best to select seeds from locally adapted, healthy, and high-yielding accessions. If these are not available, seeds from accessions adapted to similar climatic conditions should be selected. The seed stock should have an average weight above 0.7 g per seed and an oil content of above 35% (w/w) on a dry matter basis.

Roots, branching and plant architecture

Roots

Figure 21. A healthy taproot at Sunbiofuels Tanzania (photographs courtesy Richard Morgan)

Root structure is highly dependent on propagation methods, followed by soil and water availability (Liu, K., et al., 2012). What is known is that cuttings do not produce taproots, which are important in jatropha longevity and productivity (pictures are available in Van Eyck, et al., 2010). Otherwise, jatropha has strong lateral roots that develop first as the plant is developing a long taproot. If the taproot of seedlings becomes curled by staying too long in small poly bags at the seedling stage, depending on agro-climatic conditions it may not straighten or develop much depth, leaving the whole tree dwarfed and unproductive (see Volkaert, 2009, for pictures).

The topsoil in large-scale plantations is often cleared and compacted by earthmovers. This had happened in the agronomy trials (Figure 22) in Tanwat. There was higher mortality and disease in the agronomy trials in compacted soils than in the looser soils of the provenance trials. (Figure 23)

Figure 22. Compacted agronomy site Figure 23. looser peat like soils in the provenance site

One study of root formation suggested that the lateral roots reach 1.6 metres wide in the first year, whereas the taproot takes two years to reach similar depths (Rajoana, et al.,). The extent to which good taproot and plant development is dependent on good lateral root growth occurring first is unclear. When setting up a plantation, it is therefore wise to ensure that the topsoil is optimal, nutritious and open for primary lateral root growth, as well as taproot growth. Disturbing initial lateral root growth may be one of the possible reasons why preliminary observations in Nakuru suggested that plants that have been intercropped with maize in the first year did not do as well during the second year. Understanding the long-term effects on patterns of root growth of planting on ridges or in holes, on recently machine-cleared compacted land, or intercropping distances in the first or second years are important areas of future research.

Jatropha needs open, deep, well-aerated soils to develop strong root architectures. The impact of the taproot 'hitting rock' was clearly visible in Nakuru where the soil had stony patches less than 30cm below the soil surface. The trees were less than half the size of those adjacent on deep soils. As many have observed, root rot was visible in Naivasha in waterlogged clay soils. Trichoderma has been shown to assist root rot in very wet soils (Otieno, B., 2011, for DEGSJP).

Branching and plant architecture

Perhaps the dream vision of commercial breeders is to replicate whole plantations of reliable multi-branching, high fruiting, probably phorbol esther-free dwarf trees. One breeder even suggested turning jatropha into an annual/biannual crop where you 'combine' harvest and use the whole plant, and then direct seed again. This would cut harvesting costs and allow for varietal improvement. Whatever the most commercially viable dynamics of jatropha plantations turn out to be, high yields per hectare depend on optimising the number of branch endings the tree can hold year after year, so that each new branch ending produces fruit bunches with high averages of fruits per bunch.

While in this project there were many examples of stressed jatropha plants growing with a single stem, African varieties in fair or optimal conditions will usually grow two additional lateral trunks. Conventional wisdom says prune them and use them as cuttings to achieve a single stem 'hedgehog' canopy. While some have adopted pruning regimes of 50cm on the main stem, 25cm on the three resulting branches and 25cm again to start to develop the crown, once this is done it does seem that jatropha will naturally continue to branch under optimal conditions. Limited branching appears to be a result of poor agro-climatic conditions. Manual pruning on a large scale has to be well timed, well executed, and is time consuming and costly. Moreover, there is no conclusive evidence that manual pruning will universally increase yields over time. Some pruning was done in the DEGJSP project in the second year and no effect was seen. This is leading some (e.g., Zong, et al., 2010) to experiment with genetic modifications that have been successful in radically increasing branching in tobacco and petunias, as well as others experimenting with different plant growth regulators (Abdelgadir 2009, Pan 2011). Increases in the numbers of particularly female flowers, as well as asexual and bisexual flowers, were found on 6-benzyladenine treated plants, leading to a 4.5-fold increase in the fruit numbers as well as a 3% increase in oil content (Pan 2011). Whatever its effect on yields and whatever the commercial and regulatory applicability of plant growth hormones turns out to be, manual pruning may be important in establishing basic plant architecture, which can be important with respect to spacing, optimizing sunlight and for facilitating chosen harvesting techniques.

Just as there was sometimes a great difference between the growth of individual plants of the same provenance in the same small plot, there was great variation between branching and natural plant architecture between the same provenance in different sites, as well as different provenances at different sites. While there was initial excitement on the TFM plot that certain Kenyan varieties seemed to naturally branch more than others, no consistent patterns across sites were found. Results also showed the same provenance in the taller plants in Masindi had fewer branches than the same provenances under less optimal conditions in TFM. In fact, there was little consistency in any patterns, so no conclusive results can be drawn yet as to the real set of underlying factors affecting growth. Nevertheless, some anecdotal observations have been recorded.

Plants that are grown under limiting conditions do tend to maintain a single stem, whereas the same provenances grown under better conditions can often set three trunks. Some provenances do seem to branch earlier. Hailstorms, pest damage, or pinching will all lead to more branching.

Figure 24. One variety branching naturally low down

The branches of this variety were naturally so long that even the weight of a few bunches of average-sized first-year fruit (5-7 seeds) were pulling the branches to the ground. Other provenances tended to go vertical with shorter branches from a single stem.

In setting up a large 50-year jatropha plantation, it will be beneficial to schedule in 2-3 years of pilot trials to not only test the conditions, but to also work with plants that naturally develop an architecture, branch strength and branching pattern that supports the chosen plant architecture.

Soil Fertility

Over 70% of Africa's soils are said to 'have problems' (Nyathi, 2003). The idea that jatropha flourishes in marginal soils without additional care has been found to be untrue and 'marginal soils give marginal yields' in almost all circumstances. This is a key factor underlying contention about the use of nutrient-rich soils for food and higher value cash crops, rather than for biofuel production.

Perhaps the first striking factor as initial soil samples started coming in was the pH around the wild trees and the poor quality of most of the test site soils.

Table 6. pH from soil samples taken from beneath some of the selected wild jatropha trees

Mombo	Tanga	Homabay	Shimba Hills	Kibwezi	Malindi	Lindi	Lamu	Kabala	Iganga	Masaka
7.37	7.38	7.26	8.18	7.33	7.89	6.79	7.99	6.24	6.66	5.42

As many of the mother trees were well established, it begs the question as to whether wild jatropha trees prefer alkaline soils, how adaptable they arein terms of yield as far as pH is concerned, and whether the interaction of their roots, and leaf and seed waste on the surrounding soil makes it more alkaline over time. Most of the high-alkaline soils on project sites are in the coastal region; inland collection sites tend to be more acidic. This fits with others' findings. Moreover, higher altitude soils in East Africa are generally more acidic than those at lower altitudes, and that fact has consequences for differences in nutrient availability and microbial activity (Gachimbi, 2002; Maitima, J.M., 2009).

Table 7. Soil pH readings from different agroclimatic zones and altitudes in Kenya and Tanzania

	Upper Zone	**Middle Zone**	**Lower Zone**
Kenya			
Forestry	4.0		
Fallow	4.7	6.5	
Woodland		6.43	8.0
Bushland		6.4	6.6
Grassland		6.6	8.1
Coffee	4.6	4.6	
Tanzania			
Woodlots	4.7	3.8	
Pasture	4.0		
Fallow			5.1

Adapted from Maitima J M et al 2009. Showing pH readings at different altitudes

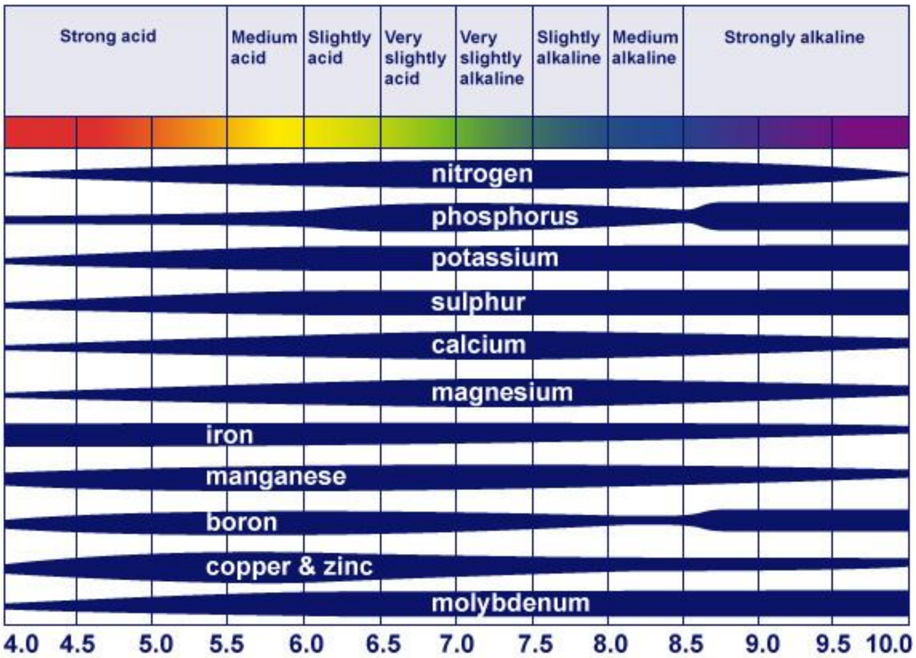


Figure 25. Graph showing biovailaibity of different micronutrients at different levels of soil pH[7].

Different pH levels affect the bioavailability of different nutrients, as well as microbiological organism activity. Alkaline soils tend to be deficient in zinc, manganese and iron, whereas acid soils tend to be deficient in molybedenum, calcium and maganesium. Potassium, sulphur and others are less affected. At the same time, the uptake of one nutrient is affected by the levels of others, as well as the organic content and microbiological activity. Scientists studying the effect of biochar found dramatic increases in Maize yields in very depleted soils by adding sawdust.

The detailed soil analysis tables in Annex Six show the range of important factors in the soils of the nines sites. The range of soil fertility was very wide and most soils had quite serious issues. One of the early soil reports from Thika indicated acidic soils and so lime was applied. However, the low night temperatures and other limiting factors resulted in minimal growth of jatropha and so no improvement was visible. The Thika and Makuyu sites are only about 30 km apart and had essentially

[7] http://www.growing-life.com/shop/pH_and_Nutrient_Availability_chart.html

the same general agro-climatic conditions over the project period, yet the growth of jatropha at the Makuyu site was nearly double that at Thika. One explanation for this may be the slightly better soils[8] at Makuyu, again demonstrating the sensitivity of jatropha to under limiting environmental conditions.

As with others (Ross, 2011; Jatropha pro, 2011), there was dramatic anecdotal and visual evidence of the impact of soil fertility. In Rea Vipingo in Kilifi, sisal waste had been dumped on a patch of soil in the middle of a neighbouring economic trial field and the growth of the plants on that more nutrient-rich patch was significantly better than plants in the same row but in less fertile soils. The trees in the picture on the left below were much taller, reaching up to 2 metres, and had flowered and fruited, producing up to 9-10 fruits in the second year on un-pruned trees. They fared much better than the more or less untended trees in the provenance trials.

Figure 26. Previous site for Sisal waste dump

Figure 27. The same line of jatropha viewed by turning around 180 degrees.

The point where the soil changes

Figure 28. Showing the point where the soils change

Figure 29. jatropha planted in an old cattle boma, July 2008

Jatropha seeds from Shimba Hills had been planted close together in a previous cattle boma in Kilifi in July 2008. They received good initial rains and grew quickly. A whole-seed oil test in 2009 showed 26.2% oil content, compared to 43% in seed picked from the original seed location in Shimba Hills when tested at the same laboratories (Analabs Kenya) at the same time.

On another non-project site at 1600 masl in Athi River Kenya, jatropha had been fed waste hydroponic rose farm water. It grew rapidly with wide girths. However, despite the growth, the seeds

[8] More detailed soils maps in the region available at http://www.flowman.nl/kiogorokenyasoilsmap.htm

were small and the oil content was only 29.7%, suggesting that while rich soils and water may offset the effects of cool night temperatures on growth, the cool temperatures may limit oil production. There have also been some discussions in the literature that very rich soils and optimal conditions can lead to lower oil yields, i.e., that, as with bioalgae, some stress is required to produce oil. The other possiblity is poor quality initial provenances, not enough sunshine, or incorrect micronutrient balance. As seen in Table 8 below, the manganese, sulphur, copper, boron and zinc levels were significantly lower than in the 'fertilised' soil (Figure 27). These observations lend some weight to the idea that one set of main nutrients influences plant growth, while another set influences fruiting and oil content (Jongschaap et al., 2007). However, plants were close and unpruned and the picture shows the long lanky branches trying to reach sunlight and the die off in the lower branches, suggesting that some pruning can help produce good architecture.

Sisal waste has been reported to contain 888 g/kg dry matter of organic matter, 180 ppm P, 2.4% nitrogen and 1800 ppm K (Van Peer A. Per Comm.). The soil analysis of the areas in Figures 26, 27 and 29 show the effect and increase in these nutrients.

Table 8: Soil Analysis of the top soil in each photograph and fertile cattle boma

Main measure	**Figure 26**	**Figure 27**	**Figure 29 Cattle Boma**
pH	8.60	5.95	7.58
P1 ppm	119	3	144
Nitrogen %	0.06	0.04	0.03
K ppm	889	113	223
Ca ppm	6165	260	994
Mg ppm	1710	82	247
Mang ppm	609	775	231
Sulphur ppm	71	14.94	11.36
Copper ppm	82.99	0.37	1.21
Boron ppm	3.47	0.81	0.66
Zinc ppm	21.72	3.83	5.74
Sodium ppm	45	77	28
FE ppm	94	134	157
Organic matter	1.23	0.93	0.65
EC (salts)	417	3.34	155

Volkaert (2009) also highlights the criticality of phosphate concentrations, not least in promoting nitrogen uptake. Jatropha is not a nitrogen fixer and needs nitrogen-rich soils for good seed production (Van Eyck, 2008). Exact levels of optimal nitrogen are being explored by companies and in research labs (Yin, et al., 2010; Yong, et al., 2010). The impact of underlying phosphate concentrations is also reported by Sun Biofuel's plantation in Mozambique, where the prime 800 hectares of previous tobacco reportedly had 60 ppm as opposed to neighbouring areas with only 2 ppm where the jatropha was not flourishing as well. It is likely that higher organic content could facilitate greater exothermic microbial activity in the soil. Richer soils could, to some extent, offset the limitations created by the number of days/nights below 15^0 C, as suggested in Mbeya and Makuyu. Thus, opting for organic manure as well as inorganic fertilizers could be an important mitigating factor in colder conditions.

Private companies, such as Sun Biofuels and Quinvita, are doing extensive fertiliser trials to discover the optimal composition, quantity and application timing for jatropha. Farmyard manure mixed with rock phosphate has been seen to create higher maize yields than farmyard manure on its own (Batiano, 1994). Similarly, research at ICRAF Kenya has shown that mulched tithonia, a common hedgerow weed in East Africa, when mixed with rock phosphate provides a complete manure.

Low available mineral phosphate levels are a limiting factor in most East African soils, and igneous and sedimentary phosphate supplies are limited. With on-going discussion on the efficient use of phosphates globally (Townsend, A. and Porder, S., 2012; Satturi, 2012), preventing topsoil erosion is an important step in maintaining existing phosphate levels. In this light, monitoring the success of projects that focus on jatropha hedges and planting specifically for preventing erosion and re-greening dry areas, with oil as a by-product (e.g., Nagaland in Amboseli) is very important, as it will also maintain potential phosphate levels needed for growth.

Mycorrhiza are fungi that enter into a symbiotic relationship with the roots of plants, including those of jatropha. Mycorrhiza take some nutrients from the plants, but they more than compensate for doing so by increasing the surface area for absorption of nutrients from the soil (especially phosphorus). It has been observed in different plants that mycorrhiza inoculation of the root zone increases growth of plants, drought tolerance and disease resistance. While not all the mechanisms are fully understood, the effects are believed to come from better nutrient absorption from soil. Jatropha has been shown to form natural associations with mycorrhiza fungi in the soil. There are claims that mycorrhiza inoculation increases the viability and growth of jatropha seedlings when planted out (Behera, et al., 2010). However, the database for such claims on jatropha is quite thin.

Figure 30. Jatropha in Kilifi on a clay loamy soil and in a sandy soil in the drought 2009

As long as there is adequate depth for full taproot growth, as well as suitable soil types with sufficient nutrients, growth may depend on the drainage and amount of rainfall. Again anecdotally, while jatropha cuttings did extremely well in the Muhaka in very sandy soils with over 1100 mm of rain in warm coastal monsoon climates (Boerstler, 2010), in the 2009 drought in Kilifi, a little further north, the extra water retention of higher clay content soils on a slope made a great difference to plant growth in comparison to very sandy soils (which were planted a little later into the drought) at the bottom of the hill.

While there are significant soil-related factors that appear to limit the potential of jatropha, such as swampy or waterlogged ground, the flexibility of the plant demands an integrated analysis on the interlocking positive and limiting factors. In the future, the 'break' points of limiting factors will be fed into dynamic models and the true costs and benefits of mitigating selected factors will be analysed. A much deeper understanding of jatropha's soil requirements, and how various interactions affect both growth and fruiting, are needed.

Leaf shedding, flowering and fruiting

Leaf shedding

Of note in the Kilifi pictures above (Figure 30) is how the trees in the better soil still had leaves and those in the poorer soils had already started to shed. This was particularly striking at Lesiolo, Nakuru, which is a dry climate. Trees close to a water tap that was used often and provided extra moisture still held their leaves, while others were bare.

Figure 31. Very localised leaf-shedding patterns within a few yards of each other in the same place at the same time

These patterns may suggest that there is a particular length of drier conditions and temperature drop that triggers leaf shedding. Anecdotally the agronomists in the project noticed that perhaps the longer and colder the dormancy period, the longer it could take for leaves to regrow once the rains come, so perhaps regeneration is triggered more by temperature than moisture. One of the challenges noticed on the coast was that, due to flourishing golden beetle populations, small new leaves were quickly eaten, which did not give the first-year plants a chance to regenerate (Awour, B. and Otieno B., pers. comm. 2010).

Flowering

Across the sites, the speed of first flowering of the first provenance was positively related to the average monthly maximum and minimum temperatures of each site, as well as the sequencing of adequate growth by the time the rains came. In Kilifi, the first flowers emerged on September 30, 2009. July, August and September were dry months, temperatures did not vary by much, and being near the equator meant that day lengths were essentially equal. July and August in Kilifi can be cloudy and windy, so perhaps the additional sunny days acted as a trigger. Otherwise, it is more as if the timing of flowering may be based on a genetic circadian 'clock' in optimal steady conditions.

Reported number of days between transplanting and the first flowering on first provenance.	Kilifi	Masindi	Manyara	Nakuru	Makuyu
	132	145	326	450	564

The first fruits were reported in Kilifi as early as November 2009, and small numbers of flowers and fruits were reported consistently through to May 2010, a 7-month period. No consistent flowering was reported in Naivasha, Mbeya, Laikipia, Makuyu or Thika. Seeds were collected from Manyara for oil testing in the third year. Counting flowers accurately was a challenging task for on-farm agronomists. Initial results do not show any consistency in flower ratios of the same provenance across different sites. See below for further discussion on some current research into flowering.

Fruiting

Compared to those produced in favourable areas, most of the fruit bunches were small, although some did reach 12-13 fruits per bunch. In unfavourable agro-ecological zones where planting was done in a drought year, the project was not established long enough to conclusively gauge differences between provenances or annual changes in fruiting that could be considered more than minimally significant.

Pollination and beehives

Bees are the primary known pollinators of jatropha and given the drastic global declines in bee populations, maintaining healthy populations for all bee-pollinated agriculture needs to be taken very seriously. As die-off from Varoa mites is also coming to Africa, using Langstroth hives allows some possibility of treatment and containment.

Ten beehives were given to each site except Masindi, since there was no one at that site to protect them. They were spread at varying distances and heights from the trials depending on the site, the main concerns being security from theft and protection from ants. Bees tend to forage within one to four km of the hive. Finding integrated pest management solutions is crucial to maintaining high pollination rates and not affecting beehives with chemicals. One of the real threats to jatropha yields is the effect on later pollination of using glycosophate herbicides for the all-important initial weed control. Also, as jatropha is seasonal, providing year-round flowering indigenous trees for forage in intermittent wildlife patches can assist maintaining healthy populations. Jatropha honey is said to be excellent and is a good way to involve surrounding communities in profiting from any plantation.

Figure 32. DEGSJP beehives within a few hundred yards of jatropha in Kibwezi, Kilifi and Nakuru

Creative plantation weed control is vital to commercial productivity, both for jatropha growth and yield, but also for pest management. Manual weeding over large areas is prohibitively costly, leaving most commercial plantations only with the option to spray herbicides. Sun Biofuels reported much less lower branch beetle damage once the grass is removed by spraying glycophosphate mixed with urea and water, enough to 'scorch' but not kill the grass, which helped prevent soil erosion. So, one of the key balancing acts for commercial plantations is managing weeds in an economically viable fashion while supporting maximum pollination by bees and other insects, such as beneficial ants.

It is worth mentioning that during the course of the project it became important to explore integrated pest management solutions. "In an orchard, diseases can also progress like a fire, and scientists have used their knowledge of fractals to figure out how many trees should be randomly excluded from an orchard's rows to prevent disease from spreading" [found as an unreferenced comment in a book on Fractals: Patterns of Chaos (Briggs, 1992)].[9] While it may sound far-fetched, there is an active branch of fractal network epidemiology and 'percolated' theory in studying the spread of human diseases (Zhang, et al., 2009; Jeger, M. et al., 2007). A Brazilian jatropha researcher also commented that 70% of the yield tended to come from 30% of the initial plantations under his study (Mike Lu, APPBM). ICRAF has also been experimenting on intercropping maize with such trees as *Acacia heyal* that leaf and flower in the dry seasons when trees like jatropha are dormant. They shed nitrogen-rich leaves that can be used as a natural fertilizer as other crops emerge from dormancy or are planted with the onset of the rains.

Especially with hand- or semi-mechanically harvested sites, there is room for some useful structured research, beyond the normal mono-plantation spacing trials, to look at the productivity of more 'clumped' jatropha 'patches' interspersed with 'disease-breaks' of fertilizer, pollinator and pest predator forage shrubs and trees, perhaps with some food intercropping. In certain types of planting regimes, greater natural disease regulation and higher productivity from well-nourished 'patches' may evolve as cost effective relative to using more intense mono-plantation pesticide and fertiliser regimes.

[9] On a request for the reference, John Briggs pointed the project manager to a web site that described the 'percolated' orchard patterns of 15th Century French monks at 60% tree cover to prevent the spread of pests and diseases before the days of insecticides and pesticides.
http://www.wahl.org/fe/HTML_version/link/FE1W/c1.htm

Many large-scale plantations do not perform uniformly and have low productivity patches, often related to specific previous activities on that site or localised changes in soil structure and depth. This suggests that it is worth exploring the impact of using some of these low-productivity areas for indigenous plant 'wildlife' patches that can house beehives and create 'disease-breaks'. What is clear is that much greater understanding of the patterns of spread, annual cycles, climatic triggers and level of economic impact of different pests and diseases can lead to more cost effective, focused spraying and control. This will also minimize the negative pollinator and environmental impacts of extensive chemical use and allow natural pest predators to emerge to control some of the pests.

Pests and diseases[10]

At the start of the project, there had been limited study of the insect fauna affecting jatropha in East Africa. This is of key importance, considering that the expansion of its cultivation will expose jatropha to new insect species. The hype suggested that jatropha was resistant to pests and diseases. In reality, jatropha has turned out to be as vulnerable as any other crop, especially once it is removed from its original habitat (including its usual pests) and placed in high density, intensive cropping systems. Economical pest management then becomes an important cost factor in commercial viability (Rao, 2006). One aspect of keeping costs manageable is to not overreact to pests and diseases that will not be economically damaging and to remain very informed and focused in pest management techniques. As will be described below, few economically damaging pest and diseases were found, particularly after the first year, and effective jatropha treatments are still being researched, standardized and regulated.

ICRAF (undated database) shows that some pests and diseases have been observed on *J. curcas* in Senegal. In Zimbabwe, powdery mildew damages leaves and flowers, *Alternaria* sp. causes premature leaf fall, and golden flea beetles eat young leaves and shoots. ICRAF data also show that *J. curcas* is a host for cassava viruses. Manoharan, et al. (2006) also reported more than a dozen pests occurring in jatropha plantations in the Udumalpettai, Erode and Mettupalayam areas of Tamil Nadu in India.

Understanding the population dynamics of insects and the responses of their natural enemies has been shown to be important ecological and applied entomological research (Berryman, 2003; Nylin, 2001). Information on the insect pests of *J. curcas* in East Africa needed to be collected in order to explore an integrated pest management regime for the species. Surveys were conducted in Eastern and Western Provinces, and in parts of the Rift Valley Nyanza and Western provinces to study the diversity of insect fauna associated with jatropha, while scheduled field assessments were conducted in the plots set up on commercial and smallholder farms in Kenya.

Table 9. Pest and natural enemy diversity in farmlands in Kenya

Pest/Location	**Kilifi**	**Makuyu**	**Naivasha**	**Thika**	**Kajiado**	**Ngurumani**	**Kitui**	**Bungoma**	**Kibwezi**	**Mbeere**
Beetle damage	+	+	+	+	+	+	+	+	+	+
Thrips	+	+	-	+	+	+	+	+		+
Red spider mites	+	+	+	+	-	+	-	+	+	
Broad mites		+	+	+		+	+		+	+
Blue bug	+	-	-	-	-	+	-	-	+	+
Leaf miner	+	+	+	+	+	+	+	+	+	+
Scale insects	+	-	-	+	-	-	-	-	-	-
Mealybugs	+	+	-	+	-	+	+	-	-	+
Pest/Location	Kilifi	Makuyu	Naivasha	Thika	Kajiado	Ngurumani	Kitui	Bungoma	Kibwezi	Mbeere
Termites	-	-	-	-	+	-	-	-	-	-

[10] This section is contributed by Beryn Otieno of KEFRI with additional comments from Dr George Francis

Pest/Location	Kilifi	Makuyu	Naivasha	Thika	Kajiado	Ngurumani	Kitui	Bungoma	Kibwezi	Mbeere
Ladybugs	+	+	+	+	+	+	+	-	-	+
Spiders	+	+	+	+	+	+	+	+	+	+
Preying mantis	+	-	-	-	-	+	-	-	-	-
Leaf spot	+	+	+	+	+	+	-	+	+	+
Powdery mildew	+	+	-	+	+	+	+	+	+	+
Root rot	-	-	+	-	-	-	+	-	+	-
Stem cankers	+	-	-	-	-	-	+	-	+	-

(Key: + = observed, - = not observed)

Most of the pests exhibited countrywide distribution with the flea beetle (*Aphthona whitefieldii*) damage being most frequently observed by farmers in all the regions visited. Cases of termite damage were very rare, occurring severely only in Kajiado and observed in Kibwezi and Kofinaf. The widest variety of pests and natural enemies were observed in Kilifi and Ngurumani. Early on in this study what was thought to be a virus turned out to be a small white mite. An unidentified stem borer, probably flying moth larvae, was found in Kilifi.

Scheduled field assessments were conducted in plots set up in commercial farms in Kenya. Counts of insect pests, their damage and natural enemies were carried out on randomly selected jatropha plants, while the damage was quantified by rating on a four point scale: 1 = no observed pest and 4 = the highest observed infestation or damage of more than 50% of the leaf area. The data was analysed in terms of presence or absence of the pests and their damage.

Results

Table 10. ANOVA tables for incidences of pest attack on various provenances[11]

Pest	Source	s.s.	m.s.	v.r.	F pr.	d.f.
Flea Beetle damage incidence	Year	2	615.40	307.70	8.33	<.001
	Site	3	18438.75	6146.25	166.48	<.001
	Provenance	26	2657.31	102.20	2.77	<.001
	Site.provenance	61	1962.18	32.17	0.87	0.747
Leaf Mines incidence						
	Year	2	9028.4	4514.2	17.38	<.001
	Site	3	11149.3	3716.4	14.30	<.001
	Provenance	26	7385.1	284.0	1.09	0.341
	Site.provenance	63	14309.2	227.1	0.87	0.746
Powdery mildew incidence						
	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Year	2	7.700	3.850	3.59	0.028
	Site	3	88.143	29.381	27.37	<.001
	Provenance	26	45.260	1.741	1.62	0.026
	Site.provenance	63	106.787	1.695	1.58	0.003

11 Standard anova terms in Table 10: s.s = sum of squares, m.s = mean square, v.r. = variance ratio, F pr. = F-ratio probability, d.f = degrees of freedom.

The damage incidence of flea beetles and powdery mildew (see photograph), varied significantly between the different provenances, while the incidence of leaf mining was not influenced by the provenances. Other key factors influencing damage to the plants by the three pests were the year and the planting site. An interaction between the site and the provenance was observed for the incidence of powdery mildew, indicating that the disease occurrence was linked to certain agro-climatic triggers that increase severity on different host provenances. One such trigger appears to be a drop in average temperatures (due to cloud cover) when humidity is still high. For instance, knowing the exact temperatures and rainfall patterns that trigger the spread of powdery mildew in that location can lead to pre-emptive, one-off spraying. Baking soda, water, neem extract and neem oil have all been shown to prevent the fungus taking hold.

Counts of insect pests, their damage and natural enemies were carried out on randomly selected Jatropha plants while the damage was quantified by rating on a four point scale where 1 had no observed pest and 4 had the highest observed infestation or damage of more than 50% of the leaf area. The data was analysed as presence or absence of the pests and their damage.

Table 11: Table showing the number of provences affected and the average percentage of pest incidence at cross all provenances at each site.

Site	Beetle damage	Thrips	Leaf mines	Powdery mildew	Leaf spots
Kilifi: Number of provenances affected.	22	22	22	16	22
Average percentage of pest incidence	63	11	50	0.9	42
Thika: Number of provenances affected.	22	1	22	22	18
Average percentage of pest incidence	31	2	12	3	1
Naivasha: Number of provenances affected.	22	13	22	0	22
Average percentage of pest incidence	14	1	42	0	2.7
Makuyu: Number of provenances affected.	20	1	9	14	17
Average percentage of pest incidence	12	3	6.5	7.5	8.2

(Data extrapolated and adapted from Ochieng, 2011)

The major pests identified from the study sites include flea beetles, leaf miners and leaf spots. Kilifi had the highest diversity of pests while Naivasha had the lowest, which also mirrors the growth of the plants. The incidence of attack of flea beetles was highest in Kilifi and lowest in Naivasha, while leaf miners were highest in Kilifi and lowest in Thika. Once the plant has reached over 1-1.5 metres, in most cases annual leaf shedding seems to take care of most leaf-eating pests. It is true that intense fruit sucking beetle attacks will lower yields. Aside from occasional fatal termite damage, grasshoppers (Makuyu) or small herbivores like dik diks (Manyara), only mealy bugs, powdery mildew and webbing insects seem to be of commercial note.

Mealybugs, once established on plants (e.g., during extended dry periods) require spraying with insecticides for control. Mealybugs are an increasingly evident problem in Africa and have ravaged Indian crops. Two species of mealybugs have been observed on jatropha in Kenya: the striped mealybug, *Ferrisia virgate,* and the common mealybug, *Planococcus* species. The adult female striped mealybugs are oval, greyish-yellow, with two long dark stripes running lengthwise on the back showing through the waxy secretion, hence the common name 'striped mealybug'. The common mealybug, however, exhibits a wide range of morphological variation, which probably represents a complex of different ecological, biological and geographical races. The main dispersal of mealybugs occurs in the first instance when wind and animals can naturally disperse them. The females are active and mobile throughout their life. All life stages may be transmitted in consignments of plant material and fruit.

Figure 33. *J.curcas* twig infested with mealy bugs. Pupa of natural enemy was observed among the colony (source: B. Otieno, KEFRI)

Mealybug damage

Infestations of mealybugs remain clustered around the terminal shoots, leaves and fruit. They suck on the plant's sap, which results in yellowing, withering and drying of plants and the shedding of leaves and fruit. The foliage and fruit also become covered with large quantities of sticky honeydew, which serves as a medium for the growth of black sooty moulds. The sooty moulds and waxy deposits also result in a reduction of photosynthetic area. Mealybugs are also known to transmit several plant viruses. The striped mealybug is highly polyphagous, attacking plant species belonging to some 150 genera in 68 families. Many of the host species belong to the Leguminosae and Euphorbiaceae. Among the hosts of economic importance are avocado, banana, black pepper, cassava, cashew, cauliflower, citrus, cocoa, coffee, cotton, egg-plant, guava, lantana, Leucaena, mango, oil palm, pigeon pea, pineapple, soybean and tomato.

Mealy bug management

To manage the insects at the beginning of a local outbreak, severely infested branches should be cut and burnt immediately. Some ladybird beetles, including *Cryptolaemus montrouzieri, Olla v-nigrum* and *Azya luteipes*, together with the syrphids, such as *Alloagrapta oblique,* are known predators of mealybugs. Chemicals such as Diazinon, Malathion, Dimethoate and Parathion are effective in controlling *F. virgata*, but they have to be sprayed repeatedly to achieve satisfactory control. Combining Parathion and Malathion with white oils makes spraying more efficient.

In this study, there was some evidence that the incidence of pests and pathogens were different in different provenances, indicating potentially different pest resistance capabilities of the provenances. Overall the results maybe also relate to there being more pests measured at sites where jatropha flourished more. However, because of its drought avoidance adaptations – for example, when it drops its leaves and stores water and nutrients in the stems under very arid conditions – newly sprouting leaves can be subject to intense beetle attack.

Some of the pests and diseases that have been identified have been found to probably have annual rhythms, and identifying these rhythms and spraying once at the right time could have a yearlong impact. Scheduled field assessments were conducted in plots set up in commercial farms in Kenya. Counts of insect pests, their damage and natural enemies were carried out on randomly selected jatropha plants. The damage was quantified by rating it on a four-point scale: 1 = no observed pest and 4 = the highest observed infestation or damage of more than 50% of the leaf area. These data were also analysed in terms of the presence or absence of the pests and their damage.

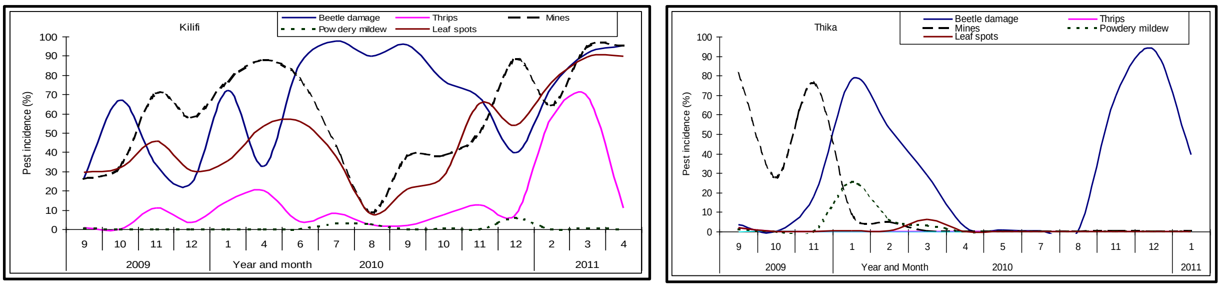


Figure 34. Seasonal trends of the damage incidences of pests on jatropha at Kilifi and Thika

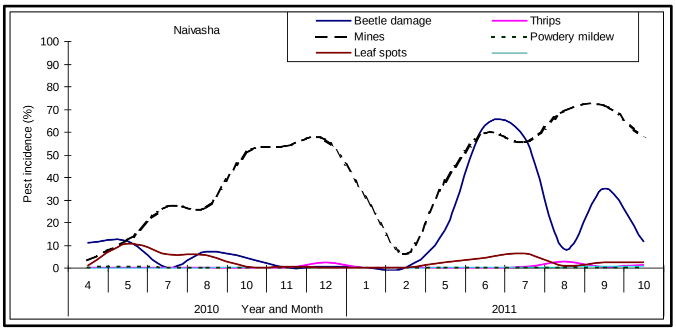


Figure 35. Seasonal trends of the damage incidences of pests on jatropha at Naivasha (X axis data points only)

The pattern of leaf-dependent beetle and leaf spots can be expected to follow leaf shedding and emerging temperature and rainfall cycles. Removing early weed competition is crucial for strong jatropha establishment and will also lessen beetle populations. Once a tree is over 1-1.5 metres high with a full canopy, then damage is usually limited to the lower leaves and is seldom economically damaging. Recent studies suggest that initial high pest pressure tends to show increased infestation for years after planting (Gagneaux, 2007). Ideally, planting jatropha in seasons when pest pressures are low will reduce the need for spraying, but given the usually short planting windows, this may not be practical.

The presence and cycles of the dominant pests and diseases of jatropha are likely to be quite site-specific. Given the cost of chemicals, investing in a complete study by a qualified entomologist during the first year set-up is likely to emerge as a cost-effective strategy. It may also bring other associated benefits, such as less environmental pollution and less pressure on beneficial pollinators and insects. A set of pests and diseases identification cards designed with Beryn Otieno of KEFRI is available on the DEGJSP website (www.degjsp.com).

Weeding and intercropping

The impact of weeding cannot be overemphasized. No consistent data were collected from project trials comparing weeded versus non-weeded plots. There were instances in economic trials where the weeds took over and the plants were not large enough to compete, and so most died or remained very stunted. Comparative weeding trials have been done, however, by D1 Oils in Zambia, and they clearly demonstrate the positive impact of weeding on plant growth.

There was not much intercropping at most sites. In Nakuru, the first year seedlings were intercropped with maize. At an altitude of 2000 metres, this seemed to create a warm microclimate and perhaps some moisture retention, so the jatropha did better than those left exposed. However, second-year growth seemed slower, perhaps because nutrients were not replenished. In the third year, perhaps because of fertilizer application, growth again improved. This is in comparison to plants that were not intercropped and maybe had to compete harder with the perennial grasses.

In Bungoma, Western Kenya, it was decided by Lesiolo to allow the surrounding smallholders to intercrop under the supervision of the local agronomist. In the process of planting their own crops, some of the leafless jatropha trees were damaged. This points to the importance of the total involvement of local smallholders in the trials and strong supervision and management of any site.[12]

Brief conclusion

Assessing the commercial viability of jatropha becomes a balancing act between the following factors and the cost of modifying those you can change in your favour:

[12] In-depth work on intercropping with small holders in Northern Tanzania can be found on www.jatropha.pro

- Enough days above limiting minimal temperatures;
- Enough days below limiting maximum temperatures;
- A seasonal rhythm and set of conditions that produce enough inputs as well as stresses to create high oil yields;
- Adequate and timely moisture;
- Adequate soil nutrition and texture/composition;
- Drainage, slope, sunlight, pollination, and pest and disease pressure;
- Using a true-to-type and well-adapted *Jatropha curcas* variety; and
- An ability to implement good agro-economic practices.

Section Three: Four key issues for a commercially successful jatropha plantation

1) Achieving targeted yields per hectare;
2) Choosing affordable harvesting techniques;
3) Maximising oil extraction and quality; and
4) Profiting from the whole plant

As described later in the report, currently two or three main commercial-scale production models are still being explored:

1) Large-scale mono-plantations;
2) 'Hybrids' that have a main plantation of 1000 or so hectares acting as a hub for outgrowers; and
3) Smaller training farms of up to 100 hectares that focus primarily on outgrowers' hedgerows.

Many reports of poor small-scale yields of between 0.1 kg per tree to less that 1 t/ha suggest to some that large-scale mono-plantations are the only way to make jatropha commercially viable. Analysis of the commercial viability of large plantations (Mitchell, D., 2011; Van Eyck, et al., 2010) highlight that success depends mainly on yield per tree per hectare, affordable harvesting costs, and the per cent oil produced during the processing. This section of the report looks at each of these in some depth.

1) Achieving targeted yields per hectare

This tree in optimal conditions in Mozambique can reportedly yield between 20-33 kg of seed, depending on weather patterns. Changing weather patterns in suboptimal conditions can anecdotally greatly affect yields. A 20-year-old tree in a garden in Kilifi in Kenya has borne no fruit in some years and in other years has been laden (Anne Robertson).

Various smallholder reports find very low yields of less than 0.5kg per tree (GTZ, 2010). Different reports vary from 0.1–15kg (James and Miller, 1993), to 0.2-2kg, (Tomatsu and Swallow, 2007; GTZ, 2010). Whatever yields researchers can get on small planting areas under the optimal planting conditions, it is still uncertain that this can translate to expanded areas. Reports that "in some small but high yielding pilot areas in China, dry fruit output is reported to be 9,000-12,000 kg/ha' have not been replicated, whereas in large plantings, the output averages only about 1800 kg per ha" (Ye, et al., 2009). Similarly, Yang et al. (2010) reported that an oil yield of 738kg/ha in small plots of selected 3-year-old trees was 2.7 times the national Chinese average. Reports on different plantations in Mexico vary from 500-4000kg/ha (Trabucco, et al., 2012).

Private research/consulting companies have seen potential of up to 6 kg per tree and are aiming to get a steady yield across larger areas with true-to-type breeding and use of best agronomic practices, with cumulative estimates of 2 tonnes of oil per hectare (Volkaert, 2009). The main focus of agronomy practices is to maximize oil production per hectare, which entails as many female flowers maturing into as many viable fruits as possible. To explore what that entails per tree, a simple model, commonly used to extrapolate yields per hectare, is given below in Table 12. The key assumptions are:

- A commercial plantation targets 2 tonsne of oil per hectare by year 10;
- That this entails a minimum of 8 tonnes of seed per hectare (Francis G, pers. comm., May 2012);
- We will suppose a 3mx4m planting space to allow tractors between rows to spray herbicide and we have seen in Sun Biofuels that at 3 metres a healthy multi-branched canopy will be

touching the adjacent tree (further research with 4mx4m is important). This spacing amounts to 843 trees per hectare; and

- Once a tree is in place, then to get the required weight of seed the tree will need (n) amount of branches with (n) amount of fruit per branch.

Table 12 below extrapolates what this actually means for each tree – based on 843 trees per hectare, 1 harvesting season, 3 seeds per fruit, seed weight of 0.65 g and oil extraction rate of 25% of seed weight. The model will assume that the desired number of hectares is set up in one planting window, which is not the case in reality beyond 1000-2000 hectares, and even then, only with very professional teams.

Table 12: The plant architectural needs and average fruit per branch for one season of 2 tonnes of jatropha straight vegetable oil (SVO) per hectare

	yr1	yr2	yr3	yr4	yr5	yr6	yr7	yr8	yr9	yr10
Oil/Tonne/ha	0	0.3	0.75	1.0	1.5	1.6	1.7	1.8	1.9	2
Seed T/Ha	0	1.2	3.0	4.0	6.0	6.4	6.8	7.2	7.6	8.0
No fruit per tree		729	1825	2435	3653	3897	4141	4384	4628	4872
Resulting no of branches required if one harvest per year										
Average no of fruit per branch										
9	0	81	202	270	405	433	460	487	514	541
12	0	60	152	202	304	324	345	365	385	406
15	0	48	121	162	243	259	276	292	308	324
20	0	36	91	121	182	194	207	219	231	243
25	0	29	73	97	146	155	165	175	185	194
Resulting no of branches required if two equal harvests per year										
Average no of fruits per branch										
9	0	41	101	135	203	217	230	244	257	271
12	0	30	76	101	152	162	173	183	193	203
15	0	24	61	81	122	130	138	146	154	162
20	0	18	46	61	91	97	104	110	116	122
25	0	15	37	49	73	78	83	88	93	97

Many are critical about this sort of modelling as jatropha trees are 'indeterminate' and it oversimplifies the complex branching, flowering and fruiting behaviour of jatropha plants. There is usually lateral branching, an extended flowering period and more than one harvest even with only one rainy season. The model is therefore only indicative and meant to act as a point of discussion on jatropha tree architecture and productivity.

The model gives indications as to why a plantation model that aims at 2 tonnes of oil per hectare (green) is hard to achieve with the harvesting model of a few larger trees giving high yields at 4mx3m spacing. Most realistic production models would look at 1 tonne of oil per hectare (purple). To harvest one tonne of oil per hectare would still need two growing seasons with 61–81 fruiting branches up to an average of 15/20 fruits per branch (red). An alternative model with 1200-1600 plants per hectare will further reduce the productivity required per plant. If 4m wide avenue spacing is important for tractor supported weeding and harvesting, 2m or 1.5m reduces the space of well-grown trees into more of a large hedge. Jatropha oil is currently valued at approximately US$1000/MT. As such, additional income from the by-products or carbon credits becomes crucial to commercial viability in many regions. Many are also rightly wary of trying to establish a global cost per hectare. The set-up and management/processing costs need to be kept within limits.

Some facts and points to note in and about this model:

1. It assumes rapid and even growth and fruit formation in the first 5 years, which has only been reported for trees in optimal conditions and soils.

2. Taking a 'hedgehog' style architecture, planted at 3m apart, growth/pruning regimes may  assume one main stem, three main branches which then branch into three, three times leading to an 'ideal' jatropha tree of 81 branches. This model could assume that to develop the branch width to carry the that that the 'birds eye' length of the branches are say, 3x50cms, 9x40cm, 27x30cms, 81x20cms, long and so the outer edge of the last branch is 140cm away from the trunk. With leaves the 150cm radius of 3 m spacing is already taken and the trees touching. Some parts of the tree on the sides are unlikely to receive much direct solar radiation needed for optimal female flower-fruit transitions. This has encouraged some plantations to experiment with different expensive hormones and chemicals shown to increase fruit set. Despite positive results, it is unlikely to be economically practicable for jatropha on any large scale.

3. If there are 64 main branches, not all branch endings will grow an inflorescence that then matures into fruits. Counts of the number of branches with fruit bunches on a tree have varied from 59-90% of branches per tree (Raden, 2008, reported in Silip, 2010) in non-bred wild trees. The mechanisms that dictate why some flower when they do and others do not are not yet understood. At the same time, it was not uncommon, especially on very healthy trees, to see an inflorescence from which three small branches have also sprouted, with fruit bunches on them as well, leading to four fruit bunches very close together at the end of one main branch.

Figure 36. Fruit bunches at branching points in Sun Biofuels Mozambique and Kilifi.

Even on first-year trees under stress, there was sometimes an inflorescence or fruit bunch at the point where three secondary branches emerged. This prompts the question as to whether the forming of the inflorescence in some way stimulates the three secondary shoots to emerge and form their own inflorescences (Ross, pers. comm., 2012). In the first photograph above, a third inflorscence is still forming on a third secondary shoot. So this branch ending will yield at least three fruit bunches. The challenge is that the fruit maturation on this one main branch may well be sequential, with the more mature seeds ready deeper inside the tree, both factors pose a challenge for economical and practical harvesting.

On a large naturally grown tree in Mozambique, this sprouting from within inflorescences, as well as the patterns of newer growth, led to mature seeds drying on the under side of the canopy while green seeds dominated on the surface. Mechanical harvesting could damage the green seeds while plucking the interior ripe seeds. Sun Biofuels experiments with trellising and different types of streamlined hedgerows did not yield commercial quantities of seed.

Figure 37. Mature seed underneath with green seed on new growth above

It is advised to plant the rows of trees in an east- west orientation to maximize solar radiation for the plants and any intercrops (Francis G., pers. comm. 2009). It has also been seen that pollen germination follows the route of the sun during the day (Srinophakun, P. et al., 2011). Even though most insects seem to be active on female flowers in the morning, peaking at around 11:00 AM, ensuring that the sun reaches the plant throughout the day may also increase the chances of flower pollination.

The above discussion on spacing and architecture suggests that experimenting with different 'open topped architectures' to enable maximum sunlight to penetrate and with around 60-70 fruiting branches in healthy trees is probably a reasonable architectural, spacing and load-bearing target (shared by Sun Biofuels, Mozambique). The huge variability of when and how even the same jatropha tree produces flowers and fruits from one season to the next has led to countless erroneous predictions of fruit weight/hectare yields. The predictions have almost always been overly optimistic, especially on any large scale. To approach the targets in the model above would currently take the best varieties in optimal conditions with the best management practices. Even then it would still be subject to the unknown variations in weather patterns, as well as the plant itself. With intense research, breeding, and genetic modifications, this may change over the next decade or two.

4. Some researchers are focusing on maximizing the number of branches through genetic modifications or plant hormones. However it is likely that the spacing, shape, load bearing, access to sunlight, and nutritional needs of the plant will create natural limits to flowering and branching.

5. To achieve enough flowering branches per hectare seems to require either having large canopied trees and a high planting density, or dwarf trees planted in high density. As mentioned above, as different plants and possibilities emerge from intense research and breeding, the final mechanics of jatropha plantation systems may turn out to be quite different from those being considered now.

6. If you have achieved the target of 2 tonnes of oil per hectare with trees having 60-70 branches and up to 15-20 fruits per branch, as discussed, 'the fruit bunches usually form at the tips (sometimes also at leaf axes) of new branches only (Francis G, pers. comm. 2012). So what happens next? The tree has filled its space and annual pruning is a very costly exercise. Does breaking off the branch end as you harvest assist next season fruiting (while raising the health and safety issue of exuding latex for manual harvesters)?

7. The actual overall limit of fruit that a tree can produce in any one agro-climatic circumstance year after year without very significant organic and fertilizer input is unknown. As far as on-going plant nutrition is concerned, it would make sense to put the seed-cake back into the system, but with jatropha oil fetching at most US$ 1000/MT on a currently purely random speculative market, many think that commercial viability will depend on selling the pressed seed-cake as either processed animal feed, fertilizer, or briquettes.

8. In arid/semiarid areas, it has been shown that wood density is less in drought conditions and so branches have less load-bearing capacity before breaking. In these conditions, fruit bunches also seldom seem to exceed 12-15 per bunch. The model would suggest that in reality yields in these conditions are unlikely to go beyond 1 tonne of jatropha straight vegetable oil per hectare

9. If full humidity and tropical monsoon climates are favoured for their seasonality, mildew becomes a major problem when humidity is still high and temperatures start to drop.

10. If you can get two reliable fruiting seasons at the same yield in a year, then your chances of success improve. Current research discussed below points to the fact that, due to different agro-climatic conditions, different seasons will produce different amounts and quality of yields. Current research also suggests that, with constant optimal weather conditions and rainfall, with no dry or cooler season, and with constant optimal conditions, jatropha yields will be lower than expected.

11. As discussed above, pruning is expensive and labour intensive. Different regimes will lead to different architectures. Cutting the trunk back to around 30cms will create a 'candelabra shape' as seen in Nakuru. Allowing initial trunk growth and then pruning back to a half a metre and pruning the three emerging branches will create more a of 'hedgehog' designed tree.

Figure 38. Unpruned varietal trials in Sun biofuels Mozambique and twice pruned plantations trees before third pruning

As shown earlier in Figure 38, trees pruned twice and awaiting a third pruning in Sun Biofuels, Mozambique, had naturally branched extensively (beyond the 64 branch-endings target) while keeping their shape. They were well laden with large fruit bunches, and 'left to themselves, with the branch end naturally breaking at harvest, they seemed to refresh naturally without extra annual pruning' (Ross S., pers. comm., 2012). To what extent they can do this over time is unknown.

12. Each planting season, more hectares are planted and the overall production averages per hectare decrease. Planting more than 1000-2000 hectares per year is a major, as well as high-risk, operation. If you 'speeded up the model and reached 2 tonnes of oil per hectare after 5 years maturity, 10,000 hectare plantations are still likely to take 15 years to reach an output of 2 tonne jatropha straight vesgetable oil per hectare. Set-up and expansion financing, as well as debt servicing and repayments, would have to be structured accordingly.

In summary, while the above model makes sense, there are many unknowns embedded within it, which means that projects just starting need to be very conservative in projecting their yield until there is proof of higher productivity across a few years, unless standardised seeds with predictable yields under defined conditions are available.

The following section briefly shares a few current findings on some of the key variables for achieving targeted yields.

Seed quality and variety

There is an increasing amount of literature on the characteristics and composition of jatropha seeds and seed oil (Tambunan, et al., 2012). Different varieties have different oil content (ranging from 8-54%) and free fatty acid compositions (Ovanda-Medina, et al., 2011). Seed size has been shown to influence germination, seedling height, rooting depth, stem diameter, number of leaves and overall biomass (Saturino, M., et al., 2005; Zaidman, et al., 2010). Quite a few companies are now claiming reliable productive varieties bred to be true-to-type (e.g., Qunivita, SGS). Those thinking of engaging in large-scale production are advised to work with these companies in doing trials on their proposed sites, while also setting up their own piloting and breeding programmes.

Pruning

Recent studies concur that 'all pruning from the ground (50, 75, and 90cms) did not have significant effects on branch number and length' (Suriharn, et al., 2011), whereas fertilizer application (<312.5kg/ha) did increase the number and length of branches, as well as fruit set (Yin, et al., 2010) and the total number of fruits and seeds 'while not affecting the intrinsic oil content' (Yong, et al., 2010). Too much fertiliser suppressed yield (Suriharn, et al., 2011). The suggestion is to prune back to 70cms after 3 years. Whether this is useful will depend to a large extent on the spacing and how the architecture maximizes sunlight to all branches and fits the chosen, most cost-effective harvesting techniques.

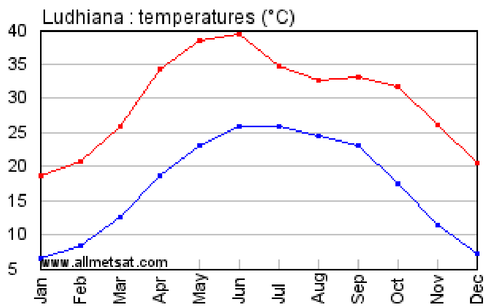
Flowering

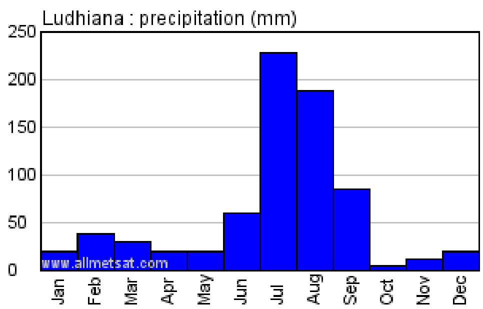
Flower buds begin to appear as small protruding structures intermingled with new leaves, usually at the terminal end of branches. Male and female flowers tend to appear at 7 and 10 days, respectively, after bud formation. On the whole, flowers are unisexual, although some genetic modifications seem to lead to increased hermaphroditic flowers. Usually, distinct female and male flowers appear on the same inflorescences with a wide range of ratios that seem to depend on genetics, climate and nutrition (Chang-Wei, 2007). The number of flowers that open on an inflorescence is also asynchronous over a range of 3-20 days. Male flowers are reported to open first (after 7 days), with a few opening every day beginning earlier in the morning (around 7:00 AM). The larger female flowers start to open 3-5 days after male flowering begins, and usually about 2 hours later (around 9:00 AM). The most insect 'visitors' are reported between the hours of 11:00 AM and 1:00 PM. A study in India (Kaur, et al., 2011) reported that the ultimate number, weight and percentage oil content of the seeds was much greater in the second flowering than the first under their particular conditions.

Table 13. Adapted from Kaur, et al., 2011

	First flowering	**Second flowering**
Altitude	244 masl	244 masl
Age of trees	4 years	4 years
Flowering span	3rd week April – 4th week June	2nd week July 2nd week November
Bud – fruit formation (days)	26 ±1,22	30 days ±2.00
Fruit set %	37	61.6
No of fruits / inflorescence	5.2 ±1.15 range 2-14	10.6 ± .96 range 6-16
Unit seed weight (g)	0.22 ±0.01	0.51 ±0.05
Oil Content	25.4%	31.1%

It seems from the average climate charts below and the extremely low reported seed weight in the first season from April-June, that rainfall was probably too low and temperatures too high to produce good fruit set (flowers blackened and died), seed weights, and oil content.





[13]

By covering two seasons instead of one [Wijaya, et al., 2009; Pranesh, et al., 2009 (time span and season not indicated); Ovinda-Medina, et al., 2009)], results indicate that regardless of the genetic basis, the number, size, and composition of inflorescences depend on the prevailing agro-climatic conditions of the specific season being studied. Highly variable oil content from the same plants in different seasons in different locations, as was found in this DEGJSP study, should be expected in less optimal agro-climatic conditions with wild seed. Professional breeders are finding consistent oil content from year to year with true-to-type selected seeds and steady optimal conditions (Volkaert V., pers. comm. 2012)

In East Africa, flowering usually commences when the rains start after a dry period and this can happen twice: in October/November, leading to mature fruits in January/February, and in March/April, leading to mature fruits in June/July/August. Higher yields can be expected after the June/July/August leaf shedding and the cooler temperatures that lead into the short rains and warmer months of December/January/February for fruit maturation.

Fruit setting and maturity

Some report between 37-61% of female flowers turning into fruits (Kaur, et al., 2011). Fruiting was visible 26.5-30.2 days after bud formation. Certain hormones and chemicals can encourage more female flowers to set into fruits. Dhillon and others report (Dhillon, 2006) that "...the period of fruit development and maturity ranged from 55 to 61 days. The results of breeding system indicated 32.9% fruit setting under selfing and 89.7% under natural pollination. The high fruit setting under open pollination revealed that the plant is capable of producing fruits through selfing (geitonogamy) and open pollination (xenogamy), such a breeding system represents facultative cross pollination."

[13] Last accessed from http://www.eldoradocountyweather.com/climate/india/Ludhiana.html on May 8, 2012

Hand-pollinated seeds (even when cross fertilized) were reported to be consistently 5% smaller than those pollinated by insects (Francis, G., pers. comm., 2011)

Pollination

One detailed study demonstrated that although jatropha mostly relies on pollination between male and female flowers of different trees, the pollen is too sticky for wind pollination and jatropha relies primarily on bees of different types, and sometimes ants are also very important to the process (Chang-Wei, et al., 2007), with cross- and open-pollination giving a significantly higher per cent of fruit setting. Jatropha can self-pollinate (which was probably the case for P18 in Tanwat), but there is some indication that this leads to much lower levels of fruit setting (up to 40-50% less) (Kaur, et al., 2011; Dhillon, et al., 2006)

In summary, maximising the numbers of fruits per hectare means achieving the maximum number of female flowers per inflorescence and ensuring maximum evolution into fruits. As demonstrated above, this depends on at least:

Good seed selection

- Selection of large fresh seeds that were harvested while yellow, from reliable adapted varieties with an oil content above 34%.
- The absence of pests and diseases on the seeds.

Good agronomy and management practices

- Creating adequate branch endings with an open architecture.
- Probably the right balance of nutrients for the whole plant and micronutrients for the fruit setting – in particular sulfur and iron, and creating the correct hormonal responses in the plant.
- Adequate pollinators at the right time.

Selecting a good site

- The optimal amount of sunlight and optimal temperatures.
- Rainfall in the right quantity at the right time before and during flowering and fruiting.
- Ensuring optimal agro-climatic conditions.

Land preparation and managing soils for commercial production

The first step of any land preparation is to conduct in-depth soil mapping and analysis so that you have a complete and accurate soil map of the area. As an example of small-scale land preparation, the details of the land preparation techniques used in laying out the jatropha trials in Laikipia following the results of soil analysis were as follows:

The land was prepared by ripping with single tyne (a shank with a blade on end) to 40cms depth. This was not always easy, as the tyne would hit hard spots and have to be lifted up and reset to go down the prescribed line. The piles of nutrients per station described below were placed on that line, so that they were mixed into the soil up to 10cms below surface. This was done with a two-disc mechanical (powered) harrow, which broke up all the clods and incorporated the nutrients in a single pass. Based on the soil analysis, 20 tonnes of well-rotted manure, 150kg of calcium carbonate, 200kg of rock phosphate and 25kg of sulphur were added per hectare. In order to correctly place the nutrients:

- Each planting 'station' and the planting spaces in between were marked out with sticks and twine.
- A 2m swathe of glycophosphate, 5 liters per hectare, was sprayed over the stations.
- A 20 litre bucket of well rotted farmyard manure was applied per station.
- Based on the soil analysis, 150g of calcium carbonate, 10g elemental sulphur, 200g of rock phosphate was applied in a small heap per planting station.

- Each of the small mounds of nutrients at each station were then augured, in order to mix the soil with the nutrients down to 40cm.

The seedlings that had stayed long in the nursery were then checked for curled taproots, and those found to be fine were planted out and any gaps were filled using seeds.

When scoping a potential commercial site, extensive soil mapping is very important. After picking the wrong soils in Ethiopia, Sun Biofuels did extensive soil mapping, along with drainage and contouring work. Instead of being planted in pits, the lines of jatropha were often planted on slightly raised ridges.

Figure 39. Drainage contours in Sun Biofuels.

Figure 40. Raised ridges with tractor space.

They also often planted in areas known to be less fertile or swampy to allow the plant itself to decide its own limits and so maximize land use.

The common wisdom is to plant in pits, and there is even heated discussion as to whether these pits should be round or square. In dry areas with well-drained soils, pits may help with water retention when it rains. At the same time, ridges may help to prevent waterlogging of flat clay soils during heavy rains. As mentioned above, the late June frosts (2.6^0 C) in Southern Tanzania settled in the pits and killed 7,000 seedlings in a few days. There may have been a higher survival rate if the seedlings had been on contoured ridges sloping down the hill so that the frost could run off and not settle. (Peter Whitehead, pers. comm., 2010)

Perhaps one of the main early large-scale commercial fallacies was the over optimistic projected speed of planting large areas because, in truth, most mono-modal rainfed systems have only a one or two month window of opportunity and in bi-modal systems it is difficult to get five months of steady rains for proper initial growth. One decision that farmers need to make relates to whether it is better to plant seed in anticipation of the rains (treated seeds have been shown to remain viable in the ground for up to one month), or to anticipate the rains by setting up a nursery and incur the high labour costs of planting out the best-established seedlings when the rains commence.

Spacing

Close spacing has been recommended for smallholder sites in less optimal areas, which may create greater vegetative cover. Overall though, as more plantations have come and gone, it is being recognized that giving jatropha the space to become a more or less self-managing tree with spacings of 4mx3m or 4mx4m is probably the most cost-effective way to plant out over large areas under favourable conditions.

Good agronomy practices

The discussions above highlight some of the basic practices that are important for reaching targeted yields and approaching commercial sustainability. There is much advice now available on the Internet, as well as some useful, publically available documents from people with experience in East and Southern Africa (e.g., van Peer, *A Jatropha Manual*, 2010; Volkaert, 2009; Jongschaap, R.E.E., in: Van Eyck, et al., 2010). A brief smallholders 'Farmers' Handbook' has been generated from this project and an interactive poster on the website can also be printed off for schools, community centres and churches (www.degjsp.com). Understanding of the basics requirements as regards soils, nutrients and agronomic management is essential. Still, there will be considerable specificity for each site.

Summary

Achieving targeted yields depends on taking a number of 'best guess' decisions and getting a wide range of conditions and practices to work for the plant. At this stage of knowledge and development of jatropha as a commercial crop, that means taking an observant and responsive hands-on management approach to evaluate many aspects that are still unknown. Good plantation management will be flexible and creative in taking an experimental approach. Plantation feasibility studies should be based on pilot studies that have tested overall annual seed and oil yields per hectare, rather than on average weight of seed per tree or on one season's or even one year's results. Projections that assume future yields based on the results from one season are very unlikely to play out in reality. As pointed out at the beginning of this report, the variability of the same season from year to year should also be factored in.

2) Lowering Harvesting costs

The main challenges

The few seeds that were ready to harvest by the end of the project time period were simply collected in bags by hand, and so this section highlights some of the issues connected with using different methods at different scales of jatropha production and points the reader to in-depth information.

After optimizing yields, one of the key challenges is that in many provenances fruits in the same bunch ripen at different stages. Wisdom has it that free fatty acids are lowest and oil content highest in yellow fruit, so one key agronomy challenge is finding out whether the bunches that do ripen at the same time, are the product of chance, genetics, or certain agro-climatic factors. The advantage of manual harvesting is the ability to be selective. The problem with manual harvesting is the cost.

Figure 41. The problem.

Figure 42. The solution.

Silip and others found that regardless of the extraction method used, oil yield increased as fruits mature, ripen and senesce (2010). Studies on the differences between chemical and mechanical extraction processes, as well as the oil content of seeds at different stages of maturation, found using crushed and warmed black seeds gave the highest oil yield (yellow seeds gave the highest using chemical extraction processes) (Silip, et al., 2010). However, further studies have found that, while the volume of oil may be similar, the free fatty acid content of seeds from yellow fruit, as well as oil pressed from such seeds, remains more stable whatever the storage temperatures. As Table 14. below demonstrates, the FFA content of stored seeds from black fruit tended to increase within 2 months at all storage temperatures, with the FFA content of seed oil from black fruit increasing even further (Tadakittisarn, S., et al., 2011). Increased moisture content has been shown to increase FFA content over time.

The 1% FFA standard for premium jatropha oil exists because oil with FFA content higher than 1% reacts quickly to produce soaps with the alkaline catalysts used in trans-esterification. The soaps then inhibit the separation of glycerin from the esters, resulting in a lower yield of biodiesel. Because it is expensive to remove FFA to below the 1% premium jatropha oil standard, harvesting is probably best scheduled when most of the seeds are yellow. That said, further studies are suggesting that higher oil content is reached by harvesting bunches of green seeds with over 10% yellow and storing them for off-tree ripening (Silip, et al., 2011). Detailed on-farm experimentation is needed to determine optimal harvesting time and methods. In practice, any harvesting techniques on a large-scale are going to pick jatropha seeds at all stages of maturity, until genetically modified varieties produce synchronous fruiting. Rapid on-farm oil extraction processing coupled with stabilizing the oil for storage, will become essential for keeping the FFA content low (and consequently costs) when producing high-grade biodiesel oil. Until a method is found to create high-yielding synchronous fruiting, different harvesting techniques need to accommodate the asynchronous patterns of readiness to harvest.

Table 14. Table showing Free Fatty Acid content of yellow and black fruit seed oil stored at different temperatures from Tadakittisarn, et al. (2011)

Table 3 FFA content of *J. curcas* oil from accession Mukdahan stored at 4, 37 and 50 ℃ for 6 mth.

Storage duration	FFA at 4 ℃ (%)		FFA at 37 ℃ (%)		FFA at 50 ℃ (%)	
(day)	OMB	OMY	OMB	OMY	OMB	OMY
0	0.90^{a}	0.17^{a}	0.90^{a}	0.17^{abc}	0.90^{a}	0.17^{a}
0.25	1.02^{a}	0.17^{a}	nd	0.17^{abc}	0.94^{a}	0.16^{a}
0.50	1.03^{a}	0.18^{a}	1.00^{a}	0.16^{a}	1.28^{b}	0.17^{a}
1	1.03^{a}	0.17^{ab}	0.97^{a}	0.18^{abc}	1.25^{b}	0.17^{abc}
1.25	1.07^{a}	0.17^{ab}	1.08^{a}	0.20^{d}	1.11^{ab}	0.18^{bcd}
2	1.05^{a}	0.17^{ab}	1.17^{ab}	0.17^{abc}	1.50^{cd}	0.19^{d}
4	1.30^{bc}	0.16^{a}	1.28^{b}	0.16^{a}	1.23^{b}	0.16^{a}
7	1.09^{ab}	0.23^{e}	1.57^{cd}	0.26^{e}	1.32^{bc}	0.23^{e}
10	1.00^{a}	0.17^{abc}	1.60^{d}	0.18^{bcd}	1.72^{d}	0.18^{bcd}
14	1.22^{b}	0.18^{bc}	1.74^{d}	0.20^{d}	1.71^{d}	0.20^{d}
28	1.31^{bc}	0.19^{bc}	2.38^{f}	0.19^{d}	1.65^{d}	0.19^{d}
69	1.43^{bc}	0.20^{d}	2.77^{f}	0.22^{e}	2.05^{e}	0.21^{d}
120	1.65^{d}	0.20^{d}	3.06^{f}	0.22^{e}	2.66^{f}	0.26^{e}
180	1.72^{de}	nd	3.36^{f}	nd	1.85^{e}	nd

Means in the same column superscripted by different letters are significantly different ($P < 0.05$).
Values are means of triplicate determinations. nd = not determined.
OMB = Oil from Mukdahan black fruit; OMY = Oil from Mukdahan yellow fruit.

Manual harvesting

Once capital set-up costs are absorbed, along with yield and extraction rates, Mitchell and others see the costs of wages – for weed control, pest and disease management, as well as for manual harvesting, as one of the most sensitive factors in attaining commercial viability in a large-scale plantation, accounting for 60-72% of annual costs in some models. (Mitchell 2011, Scharschmidt 2010). To assess the proper costs, it will also be important to define exactly what harvesting means, from picking the fruit, bagging it, and transporting it across the plantation to a drying and processing site.

Until provenances, rainfall patterns and affordable hormonal applications encourage a high enough percentage of concurrently ripe fruit, manual harvesting allows for specificity in picking only the ripe fruit. However, a recent Fact Foundation Jatropha Handbook (Fact Foundation, 2010) reported expected harvesting rates ranging from 8 kg per day to between 40-65 kg per day to a projected 144 kg per day by the best Nicaraguan pickers. Because labour is such a significant cost, in one model adding 1.2 kg more per person per day among the mid-range pickers lowered production costs by 1% (Mitchell, 2011).

There are many additional social and environmental implications attached to large-scale manual harvesting that are not included in most EIA reports, which estimate one adult picker is needed per hectare per season. These include:

- Creating a gender equitable harvesting mechanism.
- Creating short days that allow women to also tend food crops.
- Providing water and sanitation to avoid increasing local pollution.

- Providing staff with cooking fuel to prevent surrounding deforestation of intensive population in sensitive areas.

High quality and quantity yield per tree is hugely advantageous in terms of reducing costs for management, inputs, harvesting and transport, as well as increasing potential carbon credits. If you have 843 trees per hectare producing 5 kg of seed each, you can produce 4,215kg of seed per hectare. If you take a higher rate of picking at 50 kg per day, then it will take one adult 84.3 days to harvest one hectare, which covers the three-month fruiting season.

Purely hand harvested large-scale plantations in remote rural areas are difficult to envisage. When investors propose plantations of 10,000 hectares, or large plantations in undeveloped areas of Africa, for instance, which would require a three-month part-time or migrant workforce of 8,000-10,000 pickers, social and environmental non-governmental organisations become alarmed at the potential indirect impacts on the surrounding landscape. While such plantations have not yet succeeded in Africa, before changing hands, Sun Biofuels in Tanzania was noticeably bussing in villagers from 11 km away and the local authorities chose to raze an informal settlement springing up to support the workers on the edge of the plantation.

These kinds of scenarios tend to push the advantages of hybrid plantation models, such as those proposed by ABPPM in Brazil, which comprise smaller central farms and larger, well-supported and integrated out-grower schemes (Lu, 2010). Some are beginning to emerge successfully to prove the concept, such as the D1 Oils out-growers scheme in Zambia and Diligent's efforts in the less-fertile northern parts of Tanzania.

As plantations increase in size, many challenges emerge. Some of these are described above. Others include the optimal shaping of the tree, harvesting asynchronously ripening fruit, breaking branches and dealing with the latex exuding from them, and determining what to do with unripe fruit that inevitably is harvested along with the ripe fruit. Even though they will have to manage the contours and slopes, variable weather conditions, and natural tree variations, semi- and purely mechanical harvesting are being explored as alternative options to the intensity of seasonal manpower needed for manual harvesting.

Semi-mechanical harvesting

A wide variety of possible intermediate technologies have been proposed for semi-mechanical harvesting, based principally on whether you want to shake the yellow, brown and black fruits off the tree, suction them off, or wait until they fall. Clearly, if the trees need to reach about 2 metres to produce the number of branches that are strong enough to hold heavily laden fruits that can also withstand a seasonal downpour, then manual harvesters need to use some kind of raised platform or stepstool. The fewer times a manual harvester needs to pass, the more cost-effective it will be. Given that any commercial row of trees is likely to hold at least 50 trees before reaching a plantation road, and assuming one tree is going to yield on average 5kg of fruit, then each row pass will yield 250kg.

Various techniques, such as stem shaking, netting fallen fruits, strippers, robots, vacuum cleaners and other options are talked about (Fact Foundation, 2010). During the Daimler DEG project in India, a hand held 'fingered' coffee shaker was tested for harvesting approximately 2.5m 4.5-year-old jatropha plants with good architecture and about 2kg of fruit on each tree. It was, in fact, effective in that it made all the yellow, brown and black fruits fall, along with about 10% of the green fruits as waste, but still leaving most of the green fruits on the tree. One person walked ahead 'shaking' with another person walking behind collecting and bagging the fruits off the ground. Only a few trees were tried so there was no factual trial demonstrating harvest rates (kg per person per day). Still, an extrapolation from a few trees indicated a six-fold increase in kg/person/day, compared to manual harvesting (picking by hand only). The shaker however, damaged the branches.

A more practical approach was to have a person clipping fruit with a telescopic (avocado) cutter and the seed sliding down a tube of old socks (very light dry seeds get stuck) or a smooth tube of animal feed sacks into a container. The container can be on a raised platform being pulled behind a small SVO tractor along the long rows and the sacks off loaded onto major tractor-trailers on the main plantation roads. With two SVO tractors and pluckers on each side, both sides of two rows could be harvested at a time. A trained coffee plucker can pluck up to 120kg per day. Many of the first kg/person/day jatropha harvesting figures probably reflect the use of untrained pluckers.

Mechanical harvesting

There are various versions of mechanical harvesters being tested on different plantations, with most based on a 'shaking' model that presumes that the yellow, brown and black fruits will drop off more easily and the shaking will not break the branches or disturb other fruit bunches. The 'oxbo' raspberry picker style shown at left is one.[14] Creating enough branches to yield 2kg, let alone 4-6kg, of fruit from trees the size shown in the photo will be a challenge. Currently established early wild seed varieties have not so far flourished in trellising or other containment experiments and seem to need to reach a girth of around 3 metres and 2-2.5 metres height to create enough branches.

The harvester costs around US$120,000 and is expected to cover 20 hectares in a day. With a three-month growing season, on a 7-day shift one harvester could cover 1800 hectares. For a 10,000 hectare plantation, the implication is that 5 harvesters will be needed. Given the likelihood that some fruit will still come early or later than the one pass through by the harvester, it is likely that mechanical harvesting will need to be supported by semi-mechanical harvesting. While Sun Biofuels, Mozambique was given a mechanical harvester to test, to our knowledge, no mechanical harvesting has been attempted in the three countries included in this study. Other mechanical designs have been based on those used in the olive industry.

Drying and storage

As described above, the main issues around drying and storage are the quality of oil with regard to free fatty acid content. Most buyers will not purchase above 5% and the price is comparatively low between 1% and 5%. Most buyers are looking for below 1% FFA. Simple post-harvest care ensures FFA content below 1%. Ideally the fruits would be picked when yellow and dried until the water content goes below 6%. The project acquired a non-destructive calibrated water moisture measure from Finland, simplifying the measuring of moisture content. Some people say it is important not to dry fruits in direct sunlight, but work done in India revealed no deterioration of quality when fruits were dried in the direct sun. Once well dried, storage as fruit or as seed led to no detectable quality differences. One set of seeds stored in a German cellar in 1998 had exactly the same oil content when tested in 2006, and it even germinated after ten years.

Factors that can raise FFA content include:

- High moisture content left in the seeds, i.e., not properly or adequately dried.
- Exposure to post-harvest high atmospheric moisture, seeds can easily go mouldy, which results in high FFA.
- Fungal infections.

3) Maximising oil extraction and quality

This part of the report responds to the project intent to examine aspects of further processing (impacts of different types of pressing procedures on quality of oil and utilisation of the seed cake). Given that most of the jatropha was only beginning to give small yields at the end of the project, the following is based mostly on discussions with others and desk research. The project experimented with a pitebo table press, a Beilenberg press from Tanzania, and two Chinese presses shipped from

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[14] [picture taken from http://www.rakennustempo.fi/eng/?ID=1479]

China. The results from the first two were poor. The pitebo press proved quite hard to use and the Belienberg press broke quite quickly, probably because of improper mounting.

Rea Vipingo's experiments using the Chinese press were also disappointing, mostly due to clogging of the press with the cake. The first tests were carried out on May 24, 2011. The seeds used were equivalent to the project's P8 variety from the Shimba Hills and the trees were planted in 2008 in an old cattle boma with rich soil. The plants had exhibited high growth. In the lab, the original seeds oil tests indicated a 34% content.

	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**
Dry seeds weight (kg)	10	10	10	10	10
Diesel consumption litres	1.6	0.5	0.5	0.5	0.5
Oil produced litres	1.4	1.7	1.3	1.6	1.25
Seedcake produced (kg)	6.5	6.4	5.4	6.4	6.4
Percentage oil production	14	17	13	16	12.5
Percentage seed cake production	65	64	54	64	64
Percentage Losses	21	19	33	20	23.5

The second tests, carried out on June 3, 2011 and June 21, 2011 produced the following results:

	Test 6	**Test 7**	**Test 8**	**Test 9**	**Test 10**	**Test 11**	**Test 12**
Dry seeds weight (kg)	30	10	10	20	20	5	5
Diesel consumption litres	1.6	0.6	0.5	1.1	0.7	0.2	0.4
Oil produced litres	5.05	1.1	0.9	2.1	3	0.2	0
Seedcake produced (kg)	19.5	6	6.9	12.5	14	2.4	3.8
Percentage oil production	16.83	11	9	10.5%	15	4	0
Percentage seed cake production	65	60	69	62.5	70	48	76
Percentage Losses	18.17	29	22	27	155	48	24

Notes:

- Seeds harvested 2011; freshly harvested seeds produce thick viscous matter and fresh seeds produced no oil
- First ten tests on dried stored seed
- Overall average oil production – 13.48%
- Average seed cake production – 63.75%
- Average losses – 22.77%

Tests with less dried fresh seeds did not yield oil. The manual for the Chinese press was not in English, and a University of Nairobi technician who also travelled to Rea Vipingo to repair the press when it clogged up with unexpressed cake translated it.[15]

These small experiments raised some real issues that have been echoed by others. Achieving even reasonable oil yields using small presses is actually very challenging and few have gone above 21%, as

[15] Available on www.degjsp.com

mentioned, some in India to 25% which is still short of the touted 30% oil content (Brittaine, 2010; Ross S., pers. comm., 2012). These findings suggest that adequate technical support and training is necessary, at least at the beginning of a project, if the extraction rates possible (according the machinery suppliers) are to be realised.

Supporting consistent technical capacity is also not easy. There is a need to ensure only dry, clean seed with no stones or other debris is fed in; that the press is properly calibrated and adjusted; that all the cake is exuded before closing down; and that the press is well maintained. One project found that these requirements meant the permanent presence of a senior manager when pressing was underway. A growing list of possible small-scale presses with a price range of up to US$ 50,000 is available on line.[16] Some of these will be easier to use and be more effective than others.

Recent lab research (Tambunan, et al., 2012) found that crushing the kernel of jatropha before extracting the seed mechanically will give a higher oil yield and higher extraction efficiency. Higher temperature and longer preheating time also increases the yield. However, the heat should not go over 60^0 C so as not to increase viscosity and FFA content.

Using the whole seed for lighting and cooking

A 'bicycle wheel' seed cracker and a homemade hydraulic piston press that simultaneously created briquettes from the seed cake for wood fuel replacement, at first achieved an 11% oil expulsion rate with three briquettes of 296g each for 1kg of crushed seed (Boerstler, 2010). However the importance of this study was using low opportunity costs Jatropha hedges to protect the richly diverse sacred Kaya forests on the Kenyan Coast. The 'jua kali'-made 'one stop' hydraulic piston press creates jatropha straight vegetable oil for lighting in adapted 'akiba' lamps, as well as producing oil-rich uniform briquettes that were acceptable as wood biomass replacements and could also be carbonised into charcoal. The jatropha seed cake is reported to have a heating value of 25.1 MJ/kg between dry branches at 20.1MJ/Kg and wood charcoal at 25.25MJ/kg (Boerstler, 2010). This potential for harvesting oil rich seeds for both lighting and fuel purposes to replace the use of wood biomass is of great importance in East Africa and has the potential to significantly improve the livelihoods of women and children (Boestler, 2010).

Figure 43. 'bicycle wheel' seed cracker, hydrualic piston press and akiba lamp burning jatropha straight vegetable oil (compared with current kerosene lamp) in Muhaka 2010.

Commercial-scale biodiesel production

The scale and interest of the participants in the DEG Jatropha Support Programme was at the level of using jatropha straight vegetable oil in standing generators or adapted farm machinery, such as John Deere tractors. Harvests were not adequate to go deeper into oil processing. As such, the actual form of the processing of the oil seed for further energy production really depends on the form of energy or by-product use that the investor sees as most required by the market and/or commercially sustainable with lowest risks. Each further stage of processing, transport and use can incur greater costs and environmental impacts, potentially lowering the greenhouse gas benefits.

[16] http://www.jatropha.pro/jatropha_oil_expellers.htmjatropha seed

The different scales and types of processing of jatropha straight vegetable oil are now being well researched and published (e.g., Fact Foundation Handbook, 2010). Recent tests have shown that John Deere tractors and other vehicles can be adjusted to run on straight vegetable oil. In a EU test project they found that most care is required to get alkali metals (P, Ca, Mg, and also Na) below 1.5 ppm in SVO to prevent damage to the engine and to keep the emissions below prescribed levels. During the times they ran the engine, high FFA did not seem to play a big role. But they recommended keeping it low as it may corrode engine parts in the long run. If the SVO is to be converted into biodiesel, then FFA has to be below 2%, and preferably below 1% (Francis G. pers. comm. 2012).

With respect to the use of jatropha straight vegetable oil for biokerosene and aviation fuel, as well as in modern cars with very tiny iMu fuel injection apertures, adding any further insight into what is already available is beyond the technical expertise of the project team. Most modern engines can be adapted to jatropha biodiesel blends and to the corrosive properties of biodiesel (not SVO). Apparently, one of the challenges in Europe has been the ability of motorists to buy insurance cover and an agreement has been reached if the owners have certified the models for use of B10 (i.e., a 1:9 blend of biodiesel with normal diesel). Of note for Africa are attempts to link straight vegetable oil generators to multi-purpose platforms that also include solar, wind, biogas and other forms of available energy. Tatedo and Kakute are examples of sustainable community level projects using these technologies.

The oleo chemistry, trans-esterification and/or enzymatic production of jatropha oil is now well established and the information is freely available. Some people propose enzymatic processing, as opposed to the lengthy process of trans-esterification. Some have commented that the enzymes tend to break the longer ester chains into indeterminant lengths (Hoitsma, J., pers. comm. 2010). The project at this time is unaware of a commercial-scale enzymatic jatropha plant in Africa. Groups like Novozymes, Reliance, and others in America, such as Piedmont Biofuels, will be working to produce scalable multi-feedstock plants.

4) Profiting from the whole plant

Jatropha curcas seed processing routes and utilization of by-products

Jatropha curcas cultivation presently involves risk of uncertain productivity due to the lack of availability of standardised seeds and of well-developed agronomic best practices under certain growing conditions. It is therefore important to add value to the system by finding commercial uses and markets for the various by-products being generated during production of *Jatropha curcas* biodiesel. It also reduces the risk of the crop losing its attractiveness because of the decline in prices of any one product.

Important by-products include the various fractions that remain after post-harvest processing of jatropha fruits and the extraction of oil from the seeds. The important fractions are depicted in Figure 44 below.

Substances that can be extracted out of the oil and seed cake or meal, such as phorbol esters, also have a potential commercial value.

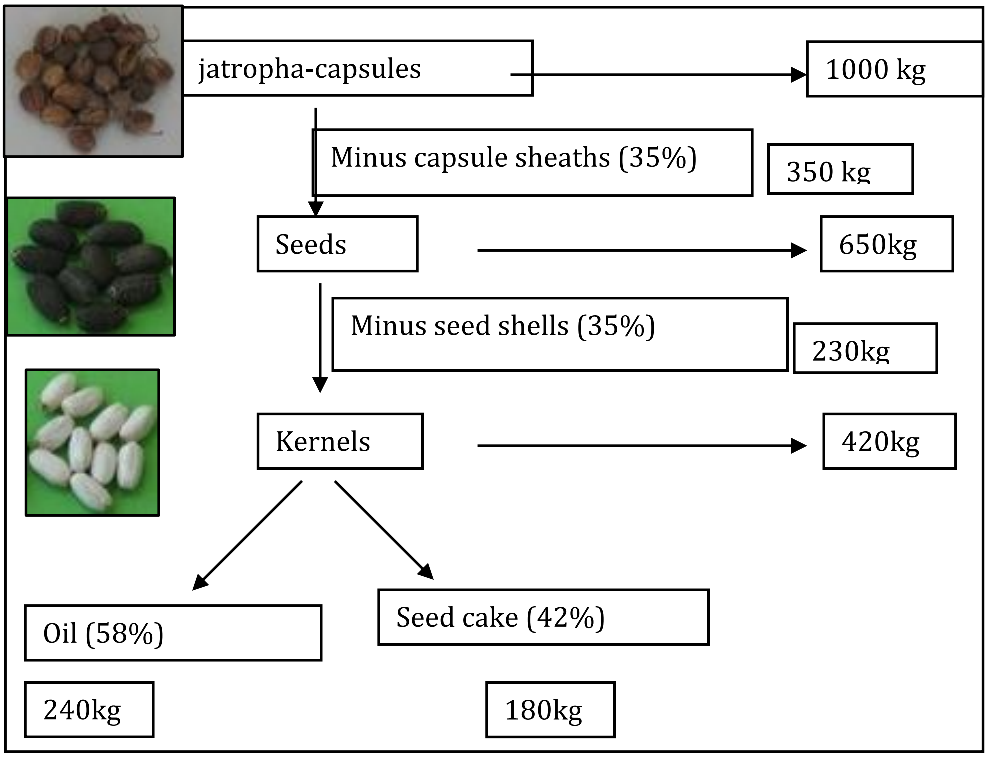

Figure 44. Various fractions of the jatropha fruit

Seed cake

The seed cake or meal that remains after extraction of oil is potentially the most valuable by-product of jatropha seed processing.

As of now, jatropha oil production occurs only on a small scale. The whole seeds are crushed using small-scale screw presses. The remaining cake has a high percentage – approximately 55% – of shell and 7-15% residual oil. This shell has very little feed value, almost eliminating the use of this cake as an animal feed ingredient. The presence of shell is, however, valuable to enable oil extraction by screw pressing. If only kernels without shell are used, it clogs between the ridges of the screw making oil yield sub-optimal. It has been seen that a partial removal of the shell after cracking the seeds before extraction may be beneficial in that wear and tear of the screw is reduced. A minimum of 15% of shell may be retained to facilitate optimal oil extraction in the seed cake.

In future, as jatropha becomes more widespread and production volumes rise, the most likely approach for oil extraction would be using a screw press combined with solvent extraction. The fatty acid composition of the oil is similar in the case of mechanically extracted or solvent-extracted oil. Solvent extraction of the cake with shell, however, generates a very deep brown colour for the oil. Other approaches being tested currently include those with pressure extraction without using organic solvents, but these are in early stages of development.

In future, it is likely that there would be two streams of seed cake production: the normal screw press that produces seed cake with shell mainly on the small scale and the larger scale production of oil from screw press plus solvent extraction/alternative methods using either completely or almost completely deshelled seeds (Figure 45).

There will therefore be two products: the shelled cake produced from the screw press that can be used as a biofertilizer cum biopesticide, and the meal produced from deshelled kernels in a solvent extraction plant that has potential for use as an animal feed ingredient after chemical treatment.

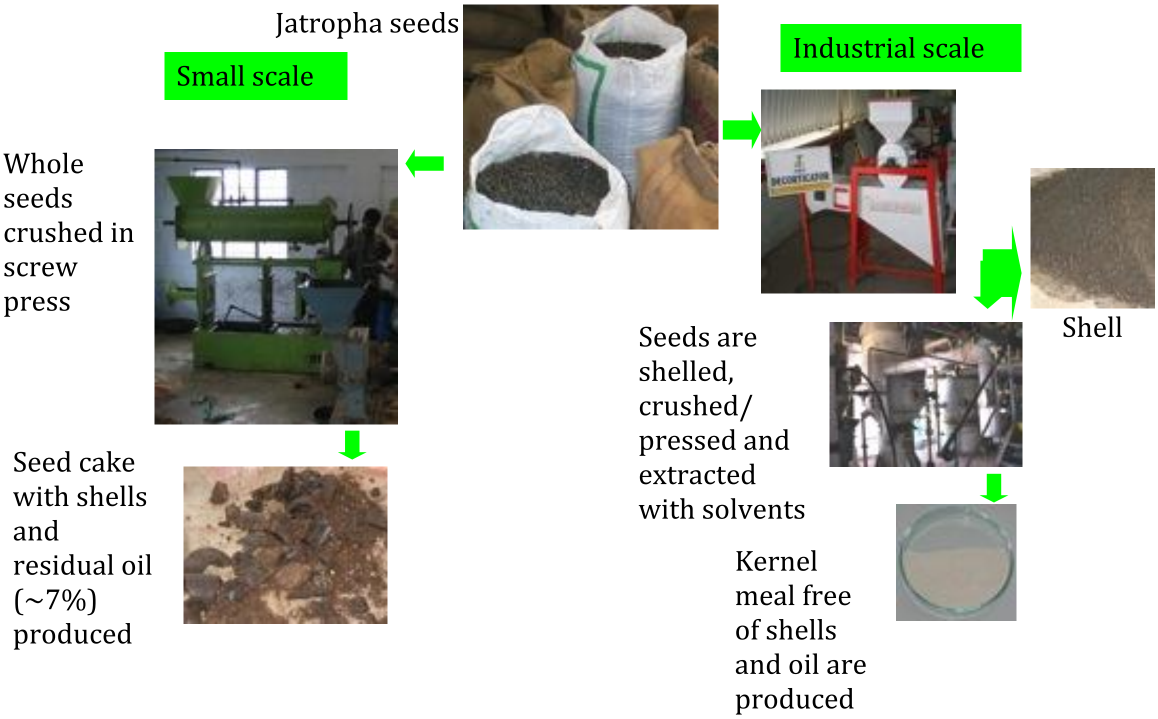

Figure 45. The two possible routes of jatropha seed processing in future.

There are also efforts from different companies to develop non-toxic varieties of jatropha that occurs naturally in Mexico. Currently they have relatively lower yields compared to the toxic varieties under similar conditions, but early results from some trials (Francis, G., pers. comm. 2012) indicate availability of non-toxic strains with high seed yield potential. Use of such non-toxic seeds (they differ from the toxic varieties only in the absence of the toxic phorbol esters) would have great advantages over the toxic varieties in that the oil produced from them could have potential dual use (as food and fuel) and the seed kernel meal will be usable as animal feed with only heat treatment, as is done in the case of soybean meal.

In the following description, the term 'seed cake' will be used for the residue remaining after extraction of oil using a screw press and 'kernel meal' will be used for describing the residue left after solvent extraction of oil from deshelled kernels. The gross chemical composition and the energy content of the seed cake and kernel meal are depicted in Tables 15 and 16.

Table 15. Average chemical composition of the seed cake including shell as obtained from the screw press

	Crude protein %	**Oil %**	**Ash %**	**Gross energy %**	**Phorbol ester mg/g**
Jatropha oil cake with shell	24-26	6-7	7	20-21	0.7

Note: Phorbol esters are the major toxins found in jatropha seeds

Table 16. Average gross chemical composition of jatropha seed kernel meal (solvent extracted, without shell) compared to soybean meal

	Crude Protein %	Lipid %	Ash %	Gross energy (MJ/kg)
Jatropha meal	57-65	< 1.0	10	18.0
Soybean meal	45-52	< 1.0	7	18.0

It can be seen that the kernel meal has a high concentration of crude protein and hence has high potential value. It also contains a high concentration of antinutrients and toxins, the most important of them being phorbol esters. Thus, the challenge of realizing the apparent high value of the kernel meal as an animal feed ingredient lies in removing or neutralizing the toxic materials in it, particularly phorbol esters. When non-toxic seeds are available these would have an advantage over toxic varieties in that the detoxification procedures can be avoided.

Possible uses of the raw seed cake produced by screw pressing of seeds or its products

As biofertilizer and biopesticide

The seed cake can be used locally as a substitute for animal manure or even chemical fertilizers. The relevant trials regarding the use of the seed cake as biofertilizer were conducted (under the project *Biofuels from Eroded Soils* in India, financed by Daimler AG and DEG). It was found that the seed cake is quite rich in macro- as well as micronutrients. It contains 3-4.5% N, 0.65-1.2% P_2O_5, 0.8-1.4% K_2O and 0.2-0.35% S. The concentration of micronutrients ranged from 800-1000, 300-500, 30-50 and 18-25ppm (mg/kg) of Fe, Mn, Zn and Cu, respectively. The seed cake was found to be beneficial, specifically for tomatoes and maize. More relevant to the small farmer model would be the finding that application of the jatropha seed cake at the rate of 3 tons per hectare per year proved to be a very good fertilizer for jatropha itself, resulting in a yield increase of above 100% over control plots where no jatropha seed cake was applied. Since the seed cake is slow to degrade, its application rate in subsequent years would be less than in the first year, in case of annual application. Like others, van Peer has reported significant increases in maize yields with the application of jatropha seed cake (van Peer, 2010) and as with others before, trials in Thailand found increased yields and could find no residues of phorbol esters when applying jatropha seed cake to vegetables (Titapiwatanakun, et al. 2011).

Currently, the jatropha seed cake produced from screw pressing has market potential in India. The volumes actually traded are small and the product commands a price of Rs. 3/kg.

As a substrate for biogas production

The high percentage of substances such as lignin, which are not degradable by bacteria, reduces the value of the seed cake as a substrate for biogas production. Reports from India, however, indicate that a gas production of 0.5 cu.mm (with about 60% methane) per kg of seed cake in conventional digesters.

Isolation of proteins from the seed cake and its purification

Because of the high amount of crude protein present in the seed cake and the potential high market value of this protein if purified into a concentrate devoid of toxic substances, research has been initiated into isolation of a protein concentrate from the seed cake (Harinder M., et al., 2008).

Briefly, the protein isolation was done by the conventional procedure of raising the pH of a seed cake solution by adding a base and then lowering it close to the iso-electric point to precipitate the proteins. After several trials, the maximum efficiency of protein isolation was observed with the following procedure. After alkaline extraction (water at pH 11; 60° C; 1 hour) of the protein present in the seed cake, the solution was brought to a pH of 4 using HCl and the solution was then kept at 4° C overnight. The extraction efficiency in the method was 17% by weight on a dry matter basis and 53% on a crude protein basis. The extract had a crude protein content of 75%.

The protein concentrate, however, contained all the antinutrients present in the seed cake, such as trypsin inhibitors, lectins, phytates, phorbol esters and phenolics. To make the protein concentrate usable, especially the phorbol esters need to be completely removed or destroyed (here again the advantages of using non-toxic seeds are obvious). The other antinutrients can be neutralised by conventional means such as heating under moist conditions and treating with phytase enzyme.

Kernel meal

As mentioned earlier, the kernel meal has high protein content (Table 16). The crude protein content of the kernel meal, at about 60%, is much higher than the most commonly used plant protein source in animal feeds, namely soybean meal (crude protein content, about 45%). In most tropical countries of Asia, Africa and Latin America, such high quality animal feed is in high demand as human consumption of meat and fish increases. The world consumption of soybean meal exceeds 130 million tonnes valued at over US$ 30 billion. Production has been increasing steadily because of increased demand from the feed industry (production in 1998 was below 100 million tonnes). Chemically detoxified toxic or non-toxic jatropha meal fit for consumption by animals can be expected to find a place in this rapidly growing market.

Regarding the availability of the kernel meal, as explained earlier, when large quantities of jatropha seeds come to the market, it is likely that the additional gain of oil over and above the quantity extractable with screw presses through solvent extraction becomes attractive and counterbalances the higher cost of solvent extraction. With this, the way is likely to be clear for the production of extracted kernel meal devoid of shells in large quantities.

The marketing of this kernel meal is likely to contribute to the profitability of the system because of the high demand and attractive price for plant-based, protein-rich animal feed ingredients. The quantity of kernel meal produced is about 0.75 tonnes per tonne of oil.

However, before the meal can be used as an animal feed ingredient the various antinutrients and toxins present in it (listed in Table 17) are to be either neutralised or removed.

Table 17. Secondary compounds present in jatropha seed meal

Component	**Quantity**
Phorbol esters (mg/g kernel)	2 – 6 <0.05 in non-toxic varieties
Total phenols (% tannic acid equivalent)	0.40
Tannins (% tannic acid equivalent)	0.04
Phytates (% dry matter)	8-10
Saponins (% diosgenin equivalent)	2-3
Trypsin inhibitor (mg trypsin inhibited per g sample)	21
Lectins (1/mg of meal that produced haemagglutination per ml of assay medium)	102

Except for the most potent toxic substance, i.e., the phorbol esters (the concentration of this is lower than 0.05mg/g in the non-toxic edible variety), the edible variety has a chemical composition that is similar to that of the toxic variety (for more information, please refer to Makkar, et al., 1998).

All the compounds except phorbol esters are present in soybean meal and other seed meals and can be eliminated or deactivated by conventional treatments, such as moist heating (120° C for 15 minutes) and addition of the enzyme phytase (commercially available as a feed additive).

The amino acid composition of the seed meal was already previously determined (Table 18) and found to be adequate. A comparison between jatropha meal and soybean reveals an almost similar pattern for all essential amino acids except lysine and sulphur-amino acids; these are lower and higher, respectively, in jatropha meals.

Table 18. Composition of important amino acids of jatropha kernel meal (g/16g N) compared with soybean meal

Aminoacids	**Soybean meal**	**Jatropha kernel meal (toxic variety)**
Methionine	1.22	1.91
Cystine	1.70	2.24
Valine	4.59	5.19
Isoleucine	4.62	4.53
Leucine	7.72	6.94
Phenylalanine	4.84	4.34
Tyrosine	3.39	2.99
Histidine	2.50	3.30
Lysine	6.08	4.28
Arginine	7.13	11.8
Threonine	3.76	3.96
Tryptophan	1.24	1.31

Taken from Makkar, et al., 1998

The deficiency of the amino acid lysine (essential for many animals) can be compensated by supplementation with the necessary amount of synthetic lysine, which is commercially available.

The quality of the non-toxic jatropha meal as an animal feed ingredient can be seen from the animal feeding experiment (with fish – common carp; Richter, N., G. Francis and K. Becker, unpublished). The secondary compounds were removed or inactivated by conventional treatment (moist heating at 120° C for 15 minutes).

It can be seen from Figure 46 that the growth performance of common carp fed the non-toxic jatropha kernel meal was comparable to that fed a fish meal-based control diet. Adding phytase enzyme, at 500FTU per kg of meal, or 0.5% by weight of synthetic lysine could enhance the nutritional quality of the meal. Even without supplementation with these substances, the diet containing the kernel meal of the edible variety appeared to be cost-effective compared with the fishmeal-based control diet.

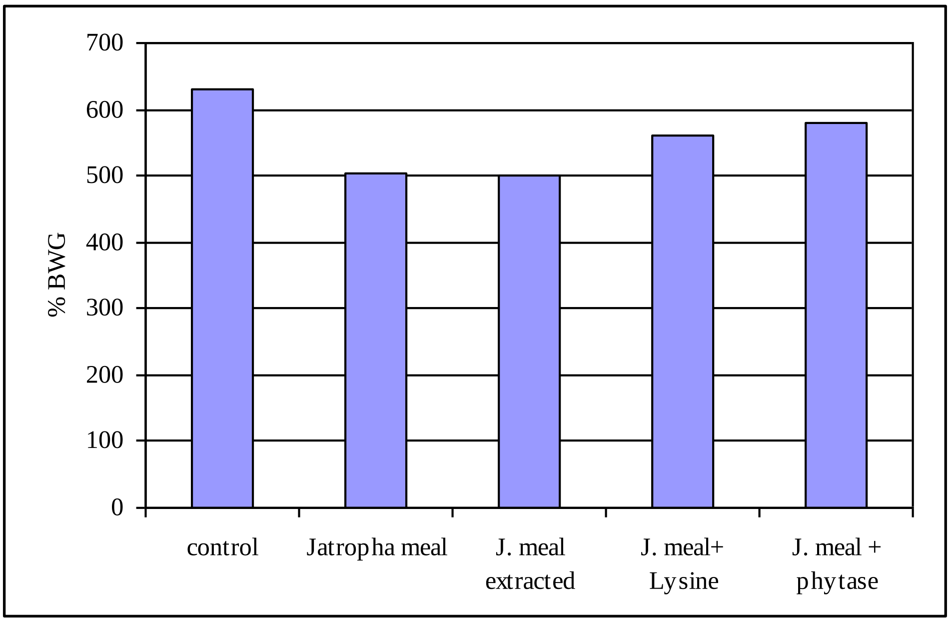

Figure 46. Percentage body weight gain of a common carp fed experimental diets containing 50% of protein supply from jatropha meal or soybean meal for 8 weeks (control feed contained 100% protein from fish meal)

Since the toxic variety is currently more widespread, its use as an animal feed ingredient may also be relevant to the profitability of jatropha systems as they exist today.

Different attempts are being made to arrive at a detoxification procedure for the toxic kernel meal. (Details of one early attempt is published in Martınez-Herrera, et al, 2006). It was found that extraction with 90% ethanol, and extraction with 90% ethanol + heat treatment with $NaHCO_3$ at 121° C for 25 minutes, effectively removed all phorbol esters from the toxic jatropha meal (see Table 5 in the publication cited above). This could be a promising lead for developing a commercial detoxification method for toxic jatropha kernel meal.

Other by-products of jatropha cultivation and biodiesel production

Seed husks
The seed husks can be used as mulch in the plantations. If dried and compacted they may also be used as fuel. It was found to have a gross energy content of 14 MJ per kg.

Seed shells
Seed shells have a high-energy content (19MJ/kg) and could supply the processing energy required for seed crushing and or trans-estrification. The seed shells would be available as a separate by-product when large-scale solvent extraction plants come into existence for processing jatropha kernels.

Derived products from jatropha

Phorbol esters
These toxic principles from jatropha seeds (can be separated from both oil and cake) are potentially high-value biodegradable natural pesticides. The most obvious uses would be in combating scistosomiasis, a disease that is widespread in Africa. Phorbol esters are highly toxic against the pond snails that are necessary for the spread of the disease. It has been reported that phorbol esters are naturally degraded in soils within a period of 7 days (Rug and Ruppel, 2000)

Extraction and utilisation of concentrated phorbol esters (Francis, G. pers. comm. 2011) – Phorbol esters are a naturally occurring family of compounds widely distributed in plants of the families Euphorbiaceae and Thymelaeceae. They are esters of tigliane diterpenes. The kernels from *J. cu*rcas contain at least four different phorbol esters. The reported biological effects of these compounds are numerous. They contribute to the inedible nature of jatropha seeds, kernels, and oil to human and most animal species. Natural poisoning with jatropha is rare because its toxic nature is widely known to people and livestock seldom browse it.

The phorbol esters can be extracted from seed cake (containing 7-15% oil) using methanol. The methanol is then evaporated in a warm water bath under reduced pressure. This raw extract can be used for biopesticide applications of phorbol ester. Once extracted, the phorbol esters are highly unstable. Antioxidants may have to be added to stabilize them.

Given that non-toxic varieties have good potential as direct poultry and animal food, intense genetic research and breeding for higher yielding, non-toxic varieties is underway (Chao, et al., 2012 – Patent application; Popluechai, et al., 2009).

Section Four: Assessing and Benefitting from Carbon Assessment and Markets

Formal markets

The Kyoto Protocol and Emission Trading

The Kyoto Protocol was set up in 1997 by the United Nations to reduce greenhouse gas (GHG) emissions. One of the principal ideas of the Kyoto protocol is that GHG emissions have a global effect, no matter where they have been produced. Consequently, GHG reduction should be implemented wherever it is most feasible.

In order to use market mechanisms for optimum cost allocation, the instrument of emission trading has been introduced to the Kyoto Protocol. The Kyoto parties issued only a limited amount of emission rights (i.e., the allowance to emit a certain amount of CO_2). This amount has to be lower than what is actually needed, forcing the parties to reduce their emissions. However, for some players it may be more expensive to reduce emissions than for others, e.g., due to already efficient technologies or due to lack of alternatives. By trading emission rights, the market can shift emission reductions to where it is most cost efficient.

Figure 47 illustrates how the price for emission rights is determined on the market and how all parties involved may benefit from emission trading. The curves show the marginal costs of emission avoidance. As a rule, saving the first tonne of CO_2 is very cheap. It may even lead to profits, e.g., in the case of energy efficiency, but for simplicity all curves start at zero. However, the more CO_2 efficient a technology already is, the more expensive it becomes to save an additional tonne of CO_2.

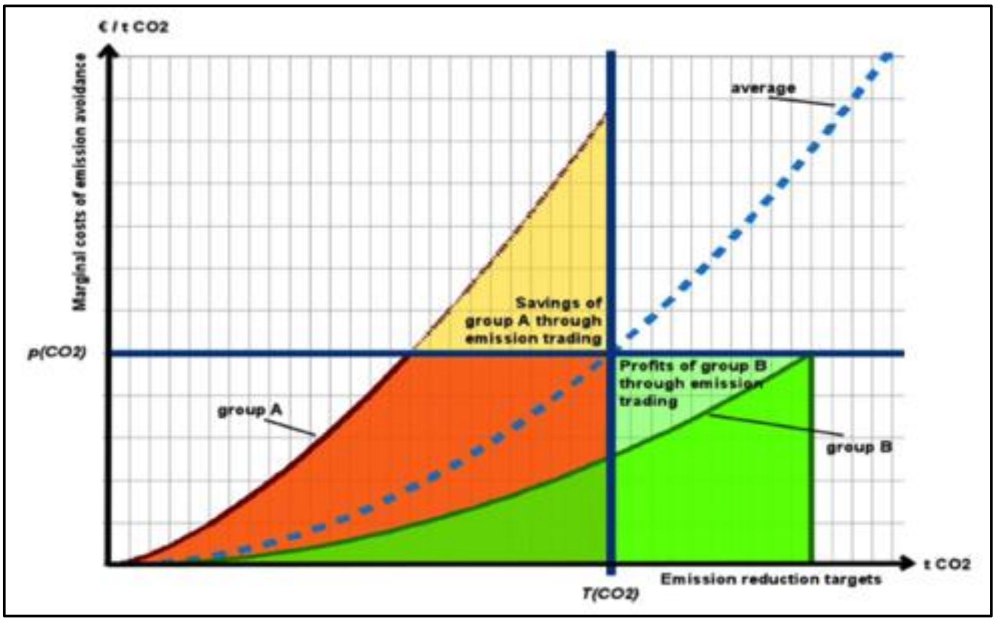

Figure 47. Price formation and benefits of trading emissions rights under the Kyoto Protocol

The curve 'average' shows the increasing costs of emission avoidance for the whole community. The vertical line $T(CO_2)$ is the global target for emission reductions. Where these two lines cross, the market price for emission rights, shown as the horizontal line $p(CO_2)$, can be established. 'Group A' represents those players with higher costs for emission avoidance, while 'Group B' has lower costs for emission avoidance than the average. As can be seen, Group A will only invest in emission saving technologies, as long as marginal costs are lower than $p(CO_2)$. To comply with the targets, it will then be more cost efficient to buy extra emission rights at a price of $p(CO_2)$. Group B, on the other hand, will even exceed their own targets, in order to produce surplus emission rights that can be sold to Group A with profits.

In summary, the reduction targets will be met by the community, but Group B will assume a share of emission savings for Group A, while the benefits from optimised cost allocation are shared through emission trading between the groups, as illustrated by the triangular areas.

The Clean Development Mechanism
While industrialised countries that have signed the Kyoto protocol have committed themselves to reduce their annual GHG emissions by 5% below the level of 1990 in average of the period 2008-2012, there are no reduction targets for developing countries. The latter retain the right to increase their GHG emissions in the course of economic growth. Nevertheless, developing countries provide many opportunities for cost-efficient emission savings, due to low technical standards that can be easily improved and due to the chance to introduce clean technologies from the beginning.

The Clean Development Mechanism (CDM) has been implemented in the Kyoto Protocol to regulate transfer of emission saving technologies to developing countries and quantification of emissions reduction for industrialised countries. All official and mandatory information as well as registered projects in the CDM context is published on the webpage cdm.unfccc.int.

During the climate conference in Durban (November 28-December 11, 2011), the world community decided to extend the Kyoto Protocol by another 5 years or more. Details still need to be negotiated at the next conference in 2012, but the continuation of the CDM is decided. The most important market for emission rights from the CDM is the European Union, which also has its own internal emission-trading scheme, regulating the obligations and options to use CDM emission rights for private companies.

How to benefit from the formal markets

Note: The CDM comes with an extensive vocabulary. Important terms will be underlined at first mention.

The highest body of the CDM is the Executive Board (EB), which ultimately decides everything, including the acceptance of CDM projects and the issuance of emission rights. A range of panels and working groups with specific responsibilities support the EB. In order to avoid arbitrariness, a catalogue of standards and procedures is defined, on which decisions are based. Supplemental guidelines and clarifications are provided. All reference is published on the CDM website. Other institutions involved in the CDM are the Designated National Authorities (DNA), which need to be established in all participating countries. The DNAs of both developing (host) and industrial countries involved in the project shall issue a Letter of Approval to the Project Participants (PP) as a prerequisite to project implementation.

Finally, the Designated Operational Entities (DOE) are independent auditors that assess if a project meets all eligibility requirements for the CDM and (later) if GHG emission reductions have been adequately quantified. Employment of a DOE is mandatory. DOEs must be accredited by the EB. Usually, they are private companies on a competitive market. A list of all DOEs accredited is publicly available on the CDM website.

At the core of a CDM project is the application of a methodology to quantify emissions reduction. A methodology is a generalised instruction for a certain type of project, including procedures and formulas for impartial calculations. Inter alia, the methodology defines how to estimate baseline emissions. The baseline scenario is the most likely scenario in absence of the project activity, i.e., baseline emissions should be the GHG emissions that would have occurred without the project. Further, the methodology defines how to measure and calculate GHG emissions that are caused by the project activity, and which parameters need to be monitored for this. The difference between baseline and project emissions is the GHG reduction attributable to the project.

A methodology must be approved by the EB in order to be used for a project. All methodologies already approved are published on the CDM website. In the case that none of the approved methodologies is applicable, because the project does not meet the eligibility criteria defined in the methodology, a revision of an approved methodology can be requested or an entirely new methodology can be proposed.

In order to implement a project under the CDM it needs to be registered. For this purpose, a Project Design Document (PDD) has to be elaborated. Templates are provided on the CDM website. The PDD includes key data like project participants and duration, a detailed technical description of the project and the application of an approved methodology. In the latter section, the generalised instructions of the methodology have to be applied to the project, specific data has to be provided and an ex-ante estimate of baseline and project emissions has to be given. Also, a monitoring plan for all data relevant for GHG emissions has to be elaborated based on the methodology. An important element of the PDD is the demonstration of additionality, which means that the project would not have been implemented anyway, regardless of GHG savings, because in this case the baseline and project scenario would be identical. Additionality can be demonstrated by a procedure called 'barrier analysis'. Further contents of the PDD include an environmental impact assessment and obtaining and consideration of local stakeholder comments.

Once the PDD is complete and national approvals have been granted by the DNAs, the project shall be validated by a DOE. Validation is usually based on the PDD, on-site visits and additional enquiries. Based on the DOE's validation report, the EB decides on registration of the project. Once the project is operational, the PPs need to apply the monitoring plan in accordance to their PDD. In periodic intervals the resulting monitoring report has to be verified by a DOE. Verification includes assessment of the documents, on-site visits and a review as to whether the project has been implemented in accordance with the PDD. Based on the verification report the DOE certifies that the emission reductions set out in the verification report were actually achieved.

Based on the certification report the EB shall instruct the CDM registry administrator to issue a corresponding amount of Certified Emission Reductions (CER). CERs are the tradeable units of the CDM, representing one tonne of CO_2-equivalent.

Table 19 provides a simple overview of the CDM project cycle with durations and costs for each step. These figures may vary in a broad range, depending on complexity and scale of a project.

Table 19. CDM project cycle

	Step and responsible	**Duration**	**Costs**
1	Project Design (PP)	4-12 months	20,000 - 100,000 € (staff + consultants)
2	National Approval (DNA)	2-6 months (may overlap)	
3	Validation (DOE)	6-12 months	10,000 - 30,000 €
4	Registration (EB)	3-6 months	Depending on project size
5	Monitoring (PP)	Variable	Staff + equipment
6	Verification (DOE)	2-4 months	7,000 - 18,000 €
7	CER issuance (EB)	3 months	

Sources: World Bank – 10 Years of Experience in Carbon Finance, Washington, 2010. Author's own estimates

Jatropha in the CDM context

A jatropha plantation established in a developing country can also contribute to GHG mitigation and thus be registered as a CDM project. In fact, there are even two mechanisms eligible: jatropha oil can substitute for fossil fuel in transport applications or for heat and electricity generation. In addition, if established on wasteland, a jatropha plantation may serve as a carbon sink, by fixing CO_2 in its woody biomass.

A number of methodologies applicable to jatropha projects have already been approved, including the use of pure jatropha oil or jatropha biodiesel in diesel engines for transport or for stationary heat and electricity generation. For example, one tonne of pure jatropha oil saves about 2.75 tonnes of CO_2 by substitution of diesel. Production of the oil, on the other hand, may cause GHG emissions of about 0.62t CO_2-equivalent, of which about three quarters are attributable to nitrous oxide emissions from fertilisation and one quarter to energy demand for oil pressing. Net savings are about 2.13 t CO_2 per t jatropha oil, or 77% if referring to the substituted fuel.

The plant dry matter of a fully-grown jatropha plantation may accumulate to about 30 tonnes per hectare. Further growth would be levelled out by the need for pruning, so that the biomass stock will remain at this point. This is equivalent to 55 t of CO_2 fixed per hectare, provided that the carbon stock of the same area was low before plantation establishment.

Figure 48 summarises the total GHG balance of 1 hectare of jatropha plantation. Twenty-one years is the maximum crediting period of a jatropha fuel CDM project according to the current rules. It has been assumed that in this period about 20t of jatropha oil per hectare can be produced. The carbon stock in biomass may reach its equilibrium within the first ten years and remain constant afterwards.

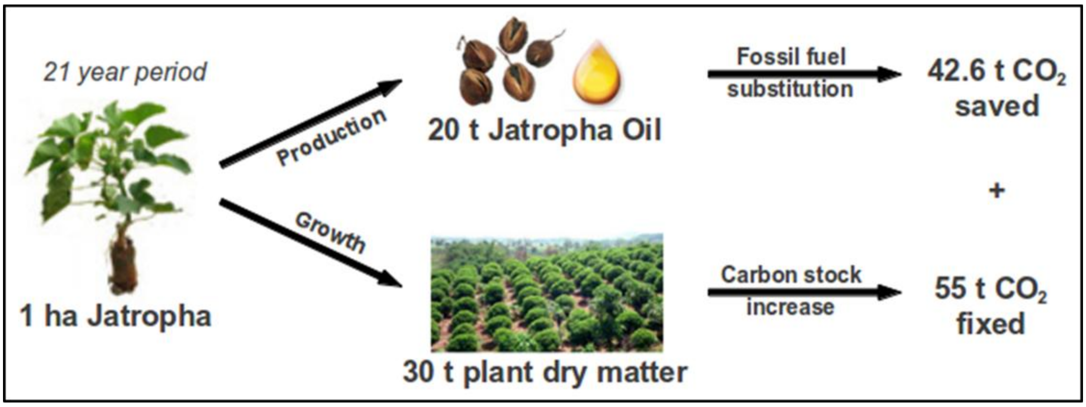

Figure 48. GHG balance of 1 ha jatropha plantation

Total GHG savings and fixation during a CDM crediting period of 21 years are at a magnitude of 100 t CO_2 per hectare of jatropha plantation. Price developments are hard to predict and dependent on policies and markets (see below), but if the last years are a representative measure, 15€/t of CO_2 might be a good estimate.

Consequently, as a rule of thumb it can be stated that revenues from CDM make up about 10% of the revenues from jatropha oil. This value can change considerably, subject to oil price development and future climate policy. Also, due to the fixed upfront costs for CDM project design, validation and registration, there are enormous economies of scale.

However, it must be noted that in addition to potential revenues, emission rights may be an important catalyst to initiate financing of projects in developing countries.

Carbon Markets

The European Union is the largest market for CERs. In spite of general uncertainties with regard to the global community, as shown during the 2011 climate conference in Durban, the next commitment period of the European Emission Trading Scheme, from 2013 to 2020, is already fixed.

What is more, the targets in this period will be ambitious. The available amount of emission rights for the European industry will decline annually, and by 2020 come down to 79% of the level of 2005. The resulting shortage of emission rights and, in parallel, an increasing share of sale by auction is likely to bull the market for emission rights. CERs from fossil fuel substitution through jatropha oil can already be sold on the European market today.

CO_2 fixation through afforestation/reforestation can also be certified under the CDM, but the resulting certificates have only limited validity, reflecting the fact that CO_2 fixation is reversible, if biomass is degraded or burnt and the carbon set free again. Although replacement of such expiring certificates is regulated under the Kyoto Protocol, they have not been admitted up to now for private players in the European System. However, there are on-going discussions to include afforestation/reforestation certificates, and European governments may well use these certificates to meet their national targets.

The World Bank's BioCarbon Fund aims at gaining experience with CDM projects that fix CO_2 in forest and agro-ecosystems. This fund, or its successors, can serve as buyers for certificates from CO_2 fixation in a jatropha plantation. In addition to the markets for Kyoto certificates, there is a wide range of options on the voluntary market. Private persons and companies that want to reduce their carbon footprint or advertise a certain product as 'climate neutral' are willing to pay for suitable carbon offsets, including those from afforestation.

On the one hand, this market is little regulated. Characteristics like credibility, additionality of CO_2 savings, avoidance of double counting, persistence of fixed carbon, and environmental and social integrity may differ and must be checked with each provider of carbon offsets. On the other hand, there are providers that subject themselves to independent auditing and have gained high public confidence. Chances of the voluntary market are that total upfront costs for a project may be lower than with the official CDM, and that project types not eligible under the CDM solely due to formal reasons may be eligible under a private scheme.

Quality standards with wide recognition include: the Verified Carbon Standard (VCS); the Gold Standard, which can be regarded as the most rigorous standard in terms of overall sustainability; and the CarbonFixStandard, which is specialised on carbon fixation in forests. Prices on the voluntary market depend on certification quality, but for high-level standards may even exceed prices of the Kyoto market.

In summary, it is recommended to carefully compare costs and potential revenues of different options for a given project before initiation. Two main points of carbon saving in the jatropha value chain is the sequestering of carbon in the trees, as once planted they can remain productive for at least 30 years or more and the potential GHG savings with the use of biodiesel in place of petro diesel

To date there is no single agreed method of assessing carbon above and below soil, not for direct and indirect land use change. The current alternative methodologies are outlined and the questions that need to be asked by would-be medium-scale plantations are outlined in a separate report.

Only the organic carbon measurements were available from the soil tests in this project and they showed no variation between years 1, 2 and 3. As most of the sites performed poorly, detailed scientific tests for carbon uptake were beyond the scope of this study.

As with all models, the estimates depend on the figures and science included. Di Oils, Zambia estimates that 12.5kg carbon is sequestered for every 100 kg of tree. Early calculations done by experts at ICRAF for DEGJSP estimated about 7 tonnes of carbon per hectare using 2x2 planting density.

Other biofuel projects, such as Novozymes consortium for out-grower's producing cassava chips in Mozambique for peri-urban cooking ethanol have been successful in collaborating with finance institutions involved in the carbon markets to pay forward the credits they will earn in lieu of cash for the project.

One CDM project has been approved in Paraguay for the replacement of diesel with castor oil biodiesel. There are some major challenges. The EU renewable energy directive (RED) set a minimum requirement of 35% in 2011 for GHG emissions savings compared to equivalent fossil fuel use. The projection is that this will rise to 50% in 2017 and 60% in 2018. Some preliminary calculations by Partner for Innovation (2010) for Sun Biofuels, using different scenarios, make a series of assumptions and project around 50% for biodiesel produced and used in Mozambique. The critical variables are the nature of the land use change, being very positive if former plantations or grasslands are used, and very negative if bush or forest is cleared for jatropha. However none of the RED default values include the carbon stock changes due to land conversion. The other major variants are the seed yield per tree (the greater the yield, the greater the GHG saving per tree), the use of inorganic fertilisers, as well as seed and oil transport costs. Again all of these factors point to the inherent benefits of setting up jatropha plantations in well-tested potentially optimal agro climatic conditions, as this avoids a whole series of extra adjustment and set-up costs, as well as provides a set of opportunities, such as access to carbon finance that will not be available in fair or limiting areas.

Section Five: Local and international regulatory frameworks and contentious issues

Local Regulatory Environments

The project manager and the team of the DEGJSP actively engaged with the Round Table on Sustainable Biofuels (RSB) during their consultations in Nairobi in 2009. Throughout 2009/2010, they also proactively engaged in driving the drafting of the Kenyan National Biodiesel strategy (Ministry of Energy, 2011) and Kenyan National Biofuels Policy/Strategy (Ministry of Energy, 2011), especially the social and environmental sections to maintain a practical 'pro-poor' policy, which also could support and regulate potential large-scale investors. The team also actively engaged in the 'Environmental Suitability and Agro-environmental Zoning of Kenya for biofuel production' with UNEP, ACTS and PISCES, particularly supporting the section on *Jatropha curcas*. One of the main purposes of the zoning document has been to advise investors which areas of Kenya are suitable and possibly available for biofuel production. Even more so, it identifies Kenya's areas of high conservation value and wildlife corridors, and in turn the areas that support Kenya's widespread tourist incomes, as unsuitable for large-scale biofuel production. The Ministry of Energy in Kenya has not yet officially adopted any of these documents.

STAKEHOLDERS' WORKSHOP FOR REVIEWING DRAFT NATIONAL BIOFUEL POLICY.

HELD AT MERICA HOTEL, NAKURU KENYA ON 1ST - 2ND FEBRUARY 2010.

The project manager participated in the consultation on biofuels in the run up to the rewording of the COP on Biodiversity in 2010, stressing the positive aspects of pro-poor biofuel production as a wood biomass replacement. They also presented the project as part of a general presentation at the EU-ACP consultation on renewable energy in preparation for the UNCCC COP in Durban in 2012.

The policymaking process was also affected by the hype about jatropha's potential, as well as the complexity and range of issues that arise around the use of large areas of land for commercial biofuel production. The Department of Renewable Energy in Kenya's Ministry of Energy is more focused on geothermal, solar, and now clean cook stove projects, given that jatropha's hyped potential has not been realized for all the reasons raised above. Although these policies also covered biomass, biogas and bioethanol, charcoal licensing and mandatory E10 pilots from sugarcane have been gazetted in separate processes. Biodiesel licensing rules were developed and later repealed as over-protective and unpractical. Over the three years, the pattern in the media was that alternative perspectives from the pro-jatropha lobby soon followed negative jatropha articles, so the uncertainty and need for facts and evidence was clear to all. The process of policy making allowed many more stakeholders to be involved and informed and to start thinking of ways of making decisions on complex issues.

When a request for a 50,000 hectare jatropha project was made in an indigenous coastal woodland area in Kenya, local and international bodies maintained their protests until a scientific report on the negative carbon emissions could be published (Mortimer, 2011). The project EIA has not been authorized by the Kenyan National Environmental Authority. While the outcome has been a success for rational science-based decision-making, without alternative energy sources and incomes, the pressures on existing forests are increasing. While the project was under discussion, the intense local logging of the woodlands for charcoal receded. The conflicts over forest rights and usage had already led to one fatality. Local people expected new income to be forthcoming. As soon as the jatropha project was abandoned, cutting the woodland for charcoal resumed. The underlying urgent problem remains. A 10,000 hectare jatropha project EIA was passed in the Tana River Delta, even though the NEMA directors who passed it were later asked to resign. This is only one of many large-scale projects proposed for the unique Tana River Delta ecosystem as part of Kenya's Vision 2030. It is already changing and will be close to the new Lamu port and northern corridor access road. Its future needs genuine and deep multi-stakeholder discussion, as it is a crucial ecosystem to many ways of life and contains unique flora and fauna. As pointed out below, in contentious issues the necessary debate and decision-making is much wider than biofuel projects.

Early assessments of 'available land' were published by the Tanzanian Investment Centre, which showed almost 1 million hectares available for investors. At one time, 23 companies were reported to have 'put in requests' for over 800,000 hectares (Temu, A. 2008). Having been the world's largest sisal producer in 1964, Tanzania was also more accustomed to the concept of successful large-scale plantations. Perhaps because of this proactive stance, and probably because of new ways being adopted by the central government to assess the use of Lana and its natural resources, a greater number of contentious large-projects have come and gone than in Kenya. Underlying the positive stance to new investment were complimentary and conflicting mandates on land and natural resource management across at least twelve different legislative areas and ministries. Issues about unclear land rights, uses, and laws between the central, regional and local authorities became hotly contested. Foreign companies were accused of exploiting the unclear circumstances, even though they asserted they were doing their best to follow the rules as presented to them. The coastal forest logging activities, and then the bankruptcy of Bioshape in Lindi in particular, raised alarm. (Gordon-MacLean, et al., 2009). This led to a ban on new projects in certain places and the setting up of a National Biofuels Task Force in 2006, with a specific policy working group evolving from the group. This group developed a set of proposed guidelines (Ministry of Energy and Mines 2008) that are now awaiting high-level government approval (Kiwele, P.M., 2009). These include:

- Institutional arrangements (biofuels one-stop centre),
- Thorough Environmental Impact Assessment (EIA),
- Land use for specific use (crops),
- Contract farming-out growers participation,
- Biofuels seeds management,
- Community engagement,
- Processing of biofuels,
- Storage and handling of biofuels,
- Transportation and distribution,
- Quality of biofuels.

As a result of the activities of the Task Force, with support from PISCES, a draft Tanzanian Biofuel Policy document is currently being revised.

In Uganda, the National Agricultural research Laboratories and the National Environmental Management Authority, with UNEP, published *The potential of biofuel in Uganda,* in which jatropha and maize potential were mapped identically. In their analysis, *Jatropha curcas* had the lowest biofuel productivity per acre and useful income compared with sugarcane, palm oil and maize. Masindi was mapped as having optimal soil, rainfall and temperatures. It is interesting that all photographs in the area from other projects also mostly show tall thin trees. This suggests that the climate encourages tall rather than bushy growth and pruning in order to shape the trees will be important.

The climatic benefits in Uganda include the fact that temperatures seldom drop below 11^0 C minimum and rainfall is more consistent and tropical. As mentioned above, this lack of seasonality may mean having to breed jatropha specifically for such a climate. Current projects such as Pegasus are importing jatropha hybrids from India. Jatropha has traditionally been used for supporting vanilla vines and as hedgerows. In the last 5-6 years, projects have tended to be based on groupings of small farmers and communities with some medium-sized farms (such as Royal Van Zanten) setting up small jatropha plantations and processing plants to meet their own diesel needs.

Press articles raise the issue of replacing food crops for jatropha without intercropping in fertile areas. So far, the government remains supportive of biofuels in general and the focus has been on resolving major controversies over land allocations for palm oil and sugarcane close to Kampala. Jatropha is mentioned once as a source of vegetable oil, along with hemp, sunflower, soya, groundnuts, castor and palm oil in the Ugandan Renewable Energy policy of 2007. "There is also the Renewable Energy Investment Plan (REIP), which is in its final stages and should be ready before the end of this financial year (June 2012). Biofuels legislation is also under way with a draft bill already presented to cabinet. It mainly focuses on production and blending of biofuels, as well as power generation (Co-gen)." (Baleke, E, pers. comm., 2012). As no 'one-stop' biofuel policies have been adopted in East Africa to date, the regulatory environment for biofuel development in all three countries still exists under separate ministries. Table 20 below highlights the main legislation and regulations under which present biofuel production would fall.[17]

Table 20. Existing regulations in Tanzania, Kenya and Uganda that affect the commerical production of Biofuels

Issue	**Main regulatory frameworks for each item in each country**		
	Tanzania	**Kenya**	**Uganda**
Producing a renewable energy	Energy policy of 2003	Energy Act 2004. 2006	The energy policy, 2002. Renewable Energy policy, 2007
Land acquisition and tenure	All large future land acquisitions to be channeled through TIC Tanzania Investment Act, 1997 is used in case of default	New constitution, Land Act and land sessional paper Nov 2009	The Constitution (1995, amended in 2005)
Agricultural Investment	Emerging crops	Draft Emerging crops policy Ministry of Agriculture	Emerging crops
Environmental compliance	National Environment Management Council (NEMC) requirements	NEMA EIA requirements	NEMA- Uganda EIA requirements. National Environment *Act* 1995. Environmental Restoration orders
Social compliance	Occupational Health & Safety Assessment Employment and Labour Relations Act, 2004	Employment act Annual budgets setting minimum wages.	Occupational safety and health act 9, 2006
Company structure and operations	Companies act 2002	Company act	Factories Act (Cap. 220).
Processing, storage and transporting of Liquid Biofuel	City/Municipal/Town Councils.	SVO not covered, Petroleum act	
Biodiesel standards	Interim biofuels standards are based on those developed by ISO.	Drafted and not adopted by Kenya Bureau of Standards.	Uganda National Bureau of Standards (UNBS) in collaboration with the Ministry of Energy & Mineral Development (MEMD)
Progress towards government adoption of specific liquid biofuels policy/ strategy	National Biofuels Task Force established in 2006	National Biodiesel committee established in 2008 Draft policy/strategy and biodiesel strategy submitted. Zoning and mapping report submitted	National Energy Committee, Renewable Energy Department and an Energy Conservation Department

International regulatory issues[18]

Long-distance transport of jatropha biodiesel does not make much sense in terms CO_2 emission mitigation, and so most jatropha biodiesel would most sensibly be used regionally or nationally

[17] More information can be found on the PISCES website: http://www.pisces.or.ke/pubs/index.html
[18] This section was contributed by Annalise Volse of PANGEA

within East Africa. Some foreign investors, however, planned projects based on returning the biodiesel for greening industry in Europe, and Europe does not have the capacity to meet its own quotas. As such, the EU policy that has had the biggest impact on the production of biofuels in East Africa is Directive 2009/28/EC on the promotion of the use of energy from renewable sources, otherwise referred to as the Renewable Energy Directive (RED) introduced in 2009. The RED provides the Member States with three important targets to be achieved by 2020. Member States are to reduce their greenhouse gas emissions by 20% below 1990 levels, 20% of energy consumption must come from renewable resources and they are to achieve a 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency. However, the Member States National Renewable Energy Action Plans have indicated that the EU will not have the capacity to produce sufficient renewable energy and that they will need to source it elsewhere. To meet the targets, imports will be required, which creates opportunities for the Least Developed Countries (LDCs) and ACP countries.

The East African countries could become important potential suppliers of renewable energy and biofuels. However, access to the EU market is heavily regulated by sustainability criteria set out in the RED to ensure biofuels have a positive impact on the environment. The Directive 2009/28/EC requires that in order to be considered in the EU target biofuels must be sourced according to sustainability criteria, which are to be found in its articles 17, 18 and 19. These criteria relate to greenhouse gas savings, not using land with a high biodiversity value or high carbon stock and agro-environmental practices. African policy makers must take into account the challenges posed by meeting these criteria if they hope to export biofuels to the EU market. As this report goes to press, the EU is considering stopping EU funding for Biofuels projects in Africa.

The RED, having initially enticed investors by securing strong demand for bioenergy until at least 2020 has now encountered problems. Increasing scientific uncertainty surrounding biofuel production has caused wariness towards investment in biofuels projects. The most problematic unresolved issue comes in the form of Indirect Land Use Change (ILUC). ILUC occurs where the expansion of croplands to support the developing bioenergy sector may result displacement of activities and land-use changes elsewhere, leading to an increase in GHG emissions, rather than a reduction. Although over the past months, European Commission officials have resolved to incorporate compensatory measures into their sustainability criteria, their specific mode of action is still to be disclosed. Inevitably, this indecision has had a destabilising effect on the international bioenergy industry. Whether the European Commission implements a specific ILUC factor or more general mitigation measure is currently under question, but it will have a major effect on the viability of future projects. If an ILUC factor is the outcome of their discussions, then first-generation biodiesel projects look to be especially disadvantaged such as palm oil, soybean, jatropha, rapeseed and sunflower oil. Given their prevalence across Africa, action would significantly and negatively affect the overall investment in biofuel production.

The EU is also currently trying to implement trade agreements that could have an impact on the biofuel sector in East Africa. The European Union–Africa, Caribbean and Pacific (EU-ACP) Economic Partnership Agreements (EPAs) are trade and development agreements under negotiation between the European Union and the seven regions of the African, Caribbean and Pacific Group of States. They replace the trade aspects of the Cotonou Agreement that had held since 2000 but were later ruled by the WTO as illegal and thus expired in 2007. A separate EPA is to be formed between each of these regions and the EU, resulting in a total of seven EU-ACP EPAs. The intention is that these agreements will help to promote growth and development in these regions, and enhance regional integration. They will contain provisions regarding trade and services in order to facilitate trade between these regions and the EU. Currently the EPA between EAC and EU has reached an agreement on market access to the EU but not on trade in services. Thus, biofuels currently being produced in this region will be exported to the EU market more freely in the future. It does not necessarily mean however, that there will be an increase in the production of biofuels, nor does it mean that an increase in the overall trade of biofuels and biofuel feedstocks will be observed.

US biofuel import and production policies are less likely to influence East African production. One or two projects, such as Bedford Biofuels, may have been initially financed by individuals taking advantage of the tax break given by the North American Biofuels Board for investing in biofuels.

Social and environmental issues

None of the sites incurred any major social or environmental issues, as almost all were brown field working farm sites or already cleared scrubland. There was little motivation for the companies to follow through on-in depth biodiversity questionnaires, although a few sites were selected by KEFRI for deeper biodiversity analysis to understand the impact of surrounding vegetation on jatropha insect populations as discussed above.

The actual social and environmental considerations of jatropha play out as a completely double edge sword depending on how and where jatropha is planted, who benefits and how it is managed. The DEGJSP project was very actively involved in raising and exploring these issues, which have been well covered in the Liquid Biofuel Policy Review (Canney Davison 2011), the draft Kenya National Biofuel Policy, especially early versions, by van Eijck, et al. (2010), and the Round Table of Sustainable Biofuels. A separate SEIA report looking specifically at East African issues is also submitted on the DEGJSP website (Nyangara, 2012)

Contentious issues

It is fair to say that East African governments and the existing regulatory and legislative frameworks were not ready to absorb the jatropha hype and sudden influx of would-be Foreign Direct Investment without raising controversy. Nevertheless, few of the contentious issues relate only to biofuels. Land tenure, ownership, rights, the use of and impact on existing ecosystem and agricultural productivity, as well as equitable and inclusive development as a nation are the same for all large-scale development projects and agricultural and extractive industries in East Africa.

When concerns are raised about biofuels in Africa, relevant contextual factors have often been omitted, which can oversimplify complex issues. The 'drivers' of the search for alternative renewable fuel are often not mentioned or done so only in passing, such as the current impact of wood biomass use, population growth and increased energy demand, climate changes triggered in part by northern hemisphere green house gas and other emissions. On the other hand, highlighting the contentious issues has been helpful in prompting the realization within East African governments that the sustainable use of natural resources at the national level is a deeply complicated and difficult issue. The issues have prompted inter-ministerial collaboration and discussion, greater involvement of many stakeholders, as well as continuous learning about new areas of science and technology. At the same time, most of the projected jatropha projects either never started or failed to reach commercial sustainability.

As the report 'The plant with the bad name' points out (Hawkins, et al., 2011), the recent history of jatropha plantations in Africa is littered with failures to reach any commercial viability before initial funding was exhausted (Canney Davison, S., 2011). As with the global biofuels industry, between a few serious people getting on with their work, it has also been littered with presenting projections based on little information as if they were fact, varying degrees of 'economies with the whole truth' and some outright fraudulent scams. In the latter category, GreenLeaf Africa and UK touting 20% returns in the first year for private investors (Greenleaf Global, You tube, 2011) was soon closed down following UK government investigations of defrauding the public of £8.2 million (The Insolvency Service, 2012). Their 'You tube' video shows only the havoc wreaked by the bulldozers. Perhaps it is a good omen that now people will look deeper into each and every issue and focus on calm, grounded, and factual discussion.

'Land grabbing'

Despite all the emotion packed into some of the issues, it was not within the purview of this project to take sides on contentious issues. Nevertheless, the project maintained a pro-poor, socially and environmentally sustainable inclusive stance. It was important to note, watch, and report on the different viewpoints informing the debate and, more than anything, attempt to provide evidence of the possible intended and unintended consequences of certain paths of action. The aim of the project has been to support those in decision-making roles to factor a precautionary principle into their decision-making processes. Aside from the on-going evolution of science-based information on jatropha's potential, one of the key constraints to achieving informed debate has been access to and the dissemination of the actual facts regarding the realities on the ground at any point in time.

The landscape of who is still in business has changed and continues to change so fast and frequently that no one, even those deeply involved, has the exact up-to-date picture. The Greenleaf Global example above highlights the challenge faced by those commenting on African biofuels and using only headlines and Internet searches to assess the actual number of hectares planted, rather than 'planned', 'proposed' or 'reported as' on the ground. To our knowledge, the only large-scale EIA approved jatropha project to date in Kenya is a controversial 10,000 hectare project for Bedford Biofuels in the Tana River Delta. Nevertheless, Friends of the Earth's report, *Africa Up for Grabs: the scale and impact of land grabbing for agrofuels* (2010), had a map of Africa showing Japanese, Belgian and Canadian Companies planning to plant up to 500,000 hectares in Kenya, even including proposed sugarcane expansion of up to 40,000 hectares. The figures do not relate to the facts on the ground. The reported map is titled 'Reported cases of land grabbing and agrofuel development across Africa'. A look at the reference section shows much reliance on Friends of the Earth's own previous work, headlines and websites.

While anti-biofuel campaigners jostle to arouse emotions, for African decisionmakers emotive discussion needs to be separated from the deep issues of inclusion and exclusion in large-scale development projects, the ownership and use of community and public land, and the power of corporations and governments to appropriate traditional lands for any large-scale agricultural, extractive, touristic, or other activity. Fostered by centuries of invasions, migrations, imperialism, and colonialism, as well as large-scale land 'allocations' to and by those in power over the last 60 years, this issue has dogged Africa for decades. Now that Africa seeks to industrialise and needs foreign investment to do so, this issue needs urgent, deep and informed discussion. Even constitutional efforts, such as in Kenya, to bring some clarity to ownership and entitlement processes, can still leave grey areas open to different interpretations, and exploitative implementation processes.

In turn, some 'land grab' reports (e.g., FOE, 2010; Sulle, 2010; Spire, 2010) seldom go deeply into patterns of overall land allocations, their histories and realities within each country, let alone into who and how many people actually currently own what percentage of arable land. Rightly or wrongly, specific cases are not contextualized or compared with other co-existing realities within a country. Given that processes of rural communal land leasing or tenure in East Africa are not that clear, an FDI company will find they often cannot win, especially when looking at green field sites. The more ethical ones will follow the rules presented to them by an agent or government representative, and then get blamed for 'taking advantage of unclear land rules'. Report writers may not 'visit villages physically' (Sulle, 2012, p. 10) and may not complete a comprehensive anonymous survey of all the surrounding villages and villagers. In some reporting, levels of analysis can get muddled and less cogent issues are included.

While so much obfuscation and 'noise' can still result in some useful and very pertinent developmental and human rights activities, it usually does not directly assist East African government ministries to align the multiple and conflicting existing laws, regulations, vested interests and different stakeholder groups. Nor does it greatly assist in developing scientific, fact-based national natural resource management and development plans. When international NGOs use figures that do not reflect the actual 'snapshot of reality' on the ground, those working within Africa to fuel pro-poor 'inclusion' not 'exclusion' (Sulle E, 2010) and to move swiftly on finding alternatives to wood fuel for cooking, cannot use these reports. 'Headline' as opposed to 'ground-survey' reporting can make government personnel more suspicious and increase the tendency to view those urging a precautionary scientific approach as also potential 'radical environmentalists' and against industrial development, when the opposite it true.

As most original jatropha projects in East Africa did not reach commercial viability before either going into receivership or being sold to other investors, reports that focus on the kinds of contracts between foreign companies and national, regional or local authorities and communities, have been useful in generating debate on what happens to the land if and when a project fails. Going bankrupt because an experimental crop did not deliver and admitting 'mistakes' were made and lessons learned is usually not against the law. One of the problems for incoming jatropha-based FDIs is that they were often run by venture capital funds that want quick returns; there was pressure to expand hectares without proof of commercial viability. City-based perceptions of commercial agriculture and spending did not fit an experimental crop on green field sites in Africa. In a bid to increase community acceptance, expectations were raised with promises of jobs, schools, roads, and medical facilities that could not be met in reality. There was much to criticize. Yet alternative solutions to the underlying urgency of rural Africa's modern energy needs, at the volume and scale now needed, were seldom proposed by those doing the criticizing.

Food for fuel

None of the trials in the DEG Jatropha Support Programme displaced food crops. The main 'food for fuel' debate focuses on using food crops such as maize and cassava for fuel. Rising food prices have been blamed in part by an increasing share of the USA's maize crop being turned into bioethanol. Recently, USDA claimed that only 1% of all maize production is used in this way; others claim it is up to 40%. The estimated percentage impact of this as the reason for food price increases has ranged from 3% overall to 35% and 75%, depending on how the figures were extrapolated.

The global food supply chain, availability and pricing is subject to many factors, not just the diversion of US maize or tropical cassava or palm oil for biofuel. These can range from fluctuating exchange rates, fluctuating and increasing oil prices increasing farm input costs, large-scale adverse weather events in key growing areas, the increasing speculation on basic food stuffs in international commodity markets, population and economic growth increasing demand, wars, and other events. The per cent impact of biofuels will depend on which figures are put into the model and how. The latter figure of 75%, 'leaked' from the World Bank and later retracted, sparked a storm of reports and analysis. With World Bank, UN and IFPRI endorsement, Action Aid used this figure and arguments as a major source in 'Meals for food' (Action Aid, 2010) to challenge all biofuel quotas and subsidies, and to advocate for a moratorium on large-scale biofuel plantations. Some engaged in renewable energy promotion have been quick to point out that the level of subsidy for renewable energy globally is very small compared with the subsidies already provided for the oil and gas fuel industries, the extraction and use of which is reported, and most would say scientifically established, as making significant contributions to human-induced climate change.

Unlike maize, soya, cassava, and palm oil, jatropha is not a dual-purpose crop. Some argue that is a good thing, especially if it can be grown on land not used for food production. Detractors argue that it is bad thing in that there are no options to grow food in jatropha plantations and if it grows, so could food. As seen above, further development of Jatropha by-products will increase the versatility of their commercial use for animal feed, fertilizer, soaps, medicines and other uses.

Another aspect of this argument discusses how those who label 'marginal' land as 'waste' or 'unused' land do not appreciate the support such land gives to marginal extended livelihoods, such as pastoralism in East Africa. For instance, the Tana River Delta has for centuries been a dry season pasture for Orma and other Kenyan tribes' cattle and the Rufiji Delta is a smallholder rice-growing area in Tanzania. In addition, taking large areas for jatropha plantations will push those already using this land into other so far untouched resources creating indirect land use change. Women and children are often most vulnerable to displacement and exploitation and youth and gender issues need to be highlighted and the impacts understood. Although very hard to measure, these changes are anticipated to negatively impact biodiversity, soil degradation and increase greenhouse gas emissions. In some cases where indigenous tropical forest has been cut down to plant biofuels, aside from the loss of biodiversity and wood and non-wood forest products, this offsets the benefits of any biofuels for decades into the future.

In summary, it is very important to protect all aspects of the rights of those presently incumbent on land, to find non-destructive modern energy solutions, and to create security and sustainable incomes for East African rural and urban populations. It is crucial to depolarize the debates, as well as to build ways of understanding and best managing the complexities. A wide range of comprehensive evidence and substantiated facts are needed in order to define and work within the delicate balance between the beneficial and negative impacts and realities of biofuels in Africa[19]

[19] A list of reports that include discussion on contentious issues are listed in the reference section and further reading and will be described in a forthcoming annotated bibliography to be available on www.degjsp.com

Section Six: The current economics and cost-benefits of different production models.

Contextual realities beyond straight economics

Before describing the pure economics of different jatropha plantations, it is important to highlight the points raised above. The drivers to explore the potential of jatropha in providing rural energy and alternatives to fossil fuels are based on the lack of any cost-effective alternatives to destructive wood fuel biomass across rural Africa, as well as the increased demand for, rising prices, periodic shortfalls, and future uncertainties of fossil fuels. The unreliability, scarcity of and lack of alternatives to current energy sources, can increase the value of a potential product such as jatropha beyond pure economics. However much jatropha production remains commercially unproven at this time, research and development, experimentation, and small- and medium-scale projects and trials are most likely to continue. The lure of succeeding in producing a local renewable energy source and liquid fuel is high.

Self sufficient communities with mostly hedgerows.

The most common use of jatropha in East Africa is as fencing, support for vanilla vines, cow shelters, and for soil conservation. In Kenya, many trees older than 30 years, and in some cases older than 50, are widespread, being used as hedgerows, sometimes against wildlife with mixed results, and in some places as medicine. It has also been used in Western and Coastal Kenya and Uganda as a support for the more lucrative vanilla crop, which can fetch up to Ksh 3,000/kg. Following the hype that jatropha can grow with minimal inputs in adverse conditions, many smallholders bought expensive seed and the crop mostly failed to yield. As demonstrated above, most of Kenya is unsuitable for commercial jatropha and since Kenya has many microclimates, in more suitable areas the difference of soils and rainfall patterns can vary within 20 kms of each other, leading to very different small-scale results (Boestler, 2011).

Projects such as: Energy Africa, Nagaland, GEF/UNDP, Vanilla Jatropha Foundation, GreenAfrica Foundation and Mpeketoni in Kenya; Tatedo, Diligent, Kakute, in Tanzania; and many other projects across East Africa have been working with smallholders with different degrees of success to develop sustainable jatropha cultivation and income generation. Small-scale NGO programmes in Kenya came under a lot of criticism in the report *Jatropha – a Reality Check* (GTZ, 2009). The reported findings on yields on 257 smallholder plots with up to 7-year-old jatropha plants across Kenya found that much of the jatropha given to or bought and planted by farmers in Kenya had failed to yield. This concurs with the finding above, that most of Kenya is potentially limiting for Jatropha. The section on 'agronomy', which looked at agro-climatic parameters, states: "a multitude of external factors related to divergent and heterogeneous management practices and inputs makes it extremely difficult to isolate the relationship between agronomic (agro-climatic) conditions and yields." The DEGSJP experience suggests that future research can benefit by not just asking farmers how and when they planted what kind of jatropha, (seeds, seedlings, cuttings) but also map the exact agro climatic conditions and rainfall patterns and growth in the following months. What the 'Reality Check' also emphasizes is that, aside from starting in potentially optimal locations, smallholder projects need to be structured to provide extensive and on-going training and support in agronomy and management practices. This is true whether they are centred around training farms, as in DI Oils, Zambia, with only smallholder groups or focused more on buying seed, such as Diligent.

An in-depth cost-benefit study was carried out relating to smallholders working with Energy Africa in the Shimba Hills in Kwale District (Mogaka, et al., 2009). Due to the limited jatropha value chain in Kenya, a financial cost-benefit analysis was carried out. The analysis was based mostly on the costs of feedstock production including land preparation, planting, weeding, pruning, harvesting, and disease and pest control. The only direct and measurable benefit was obtained from the sale of seed at prevailing market prices.

With 200 contracted farmers around Energy Africa, the dominant farming system was intercropping jatropha with annual food crops such as cassava, beans and maize. There have been low yields of up to only 0.1 kg per plant with only one pesticide used on a reactive basis. The breakeven point with seed selling at Ksh 50/kg was 1.9 kg per plant. Compared with oranges and maize, the study showed jatropha only had positive margins when they could sell the seed for Ksh 100/kg (~US$ 1.20) and made losses at Ksh 10/kg – the 'recommended' price for buying jatropha seed for commercial biodiesel production. It is notable that the DEGJSP project initially bought small quantities of seed from a Kenyan specialist jatropha NGO at Ksh 1500/kg and was offered more from another at US$ 35/kg.

This economic analysis concurs with Wekesa, et al. (2010) that pro-poor jatropha production for selling seeds at Ksh 10/kg is not economically viable in any of the four main regions of Kenya. The scenario changes in 'advanced' pro-poor production models where jatropha is grown for straight vegetable oil and kerosene substitution. Then it can become economically viable in the 10th year, still aided by some intercropping. Similarly, looking at net present values (NPV) and internal rates of return (IRR) for different yield scenarios, Loos, et al. (2008) concluded that smallholders can only profit with yields of between 2-3 tonnes per hectare.

That currently leaves a few of the out-grower schemes and those NGOs that are dedicated to jatropha still working. As far as large-scale projects go, Bedford Biofuels is in the set-up phase in Tana River, NII (who asked for the Dakatcha woodlands and were refused) has apparently moved their equipment further inland, and there has been unverified talk of a jatropha project around Galana ranch next to Tsavo. There are those within KEFRI and the universities who continue to engage in jatropha breeding and research as part of an overall search for a commercially viable biofuel feedstock in Kenya.

Supported out-grower schemes.

Out-grower schemes have all the advantages of not incurring the challenges of acquiring land and company land-tenure issues. They are also very attractive from the point of view of offsetting some of the critics of jatropha by providing rural development and income when they work. Much has been written about Diligent Oils in Tanzania (Balkema, 2011; Van Eyck, 2010; Mitchell, 2011). It is reported that Diligent bought almost 400 tonnes of jatropha seed in 2011, producing almost 100 tonnes of jatropha oil. Some has been exported and much is used for soap production. Diligent is reported to expect to triple their production in 2012. However, they face competition from other groups also buying seeds (van Peer, pers. comm.2012). Diligent is not reported to be financially self-sustaining.

Also in Tanzania, KAKUTE disseminates the know-how concerning 'The Jatropha System' and produces jatropha soap on an industrial scale. Dissemination is done within a project called 'ARI-Monduli' (Alternative Resources of Income for Monduli women). This project is financed by the McKnight Foundation (USA) and is executed in close cooperation with Heifer International Foundation (USA). Since 2002, a number of women's groups have set up nurseries, demonstration plots, an oil-pressing centre, and soap-making activities. Seedlings trade at about Tsh 50 each and oil at about US$ 2/litre. Twenty litres per month produces about 40kg of soap, which can sell for US$ 120. KAKUTE is in charge of this project. To assure that the jatropha activities stay in the hands of the women, Kakute refuses to buy seeds from men. So if men want to get money by collecting jatropha seeds, they have to sell them first to the women. A detailed analysis of the interaction between the different stakeholders, as well as a detailed analysis of jatropha products has been carried out by Messemaker (2008) and Wahl et al (2009). Both conclude that jatropha needs many more inputs than previously stated and that the value chain and benefit to smallholders, beyond traditional hedges, is still in very incipient stages.

KAKUTE tries to use jatropha to combat erosion between Arusha and Lake Manyara. A water line for cattle was installed there, which led to overgrazing around the water basin and consequently to deep erosion grooves. KAKUTE tries to plant jatropha to reduce the erosion, but is having little success, since the origin of the overgrazing – the water source – still exists.

Jatropha Pro is a project working in Tanzania as part of a feasibility study from the fair trade organization of Max Havelaar. They chose to work with existing coffee cooperatives that have over 100,000 members, mainly subsistence farmers. The challenge of the project is to encourage these farmers to produce jatropha seeds in an area that they usually use for growing food. The only way to justify this model is to use the jatropha seedcake to increase food production as a compensation for the area taken by jatropha. In a couple of demonstration trials using jatropha seedcake as a fertilizer, the maize yield increased from1.5 to 4.3 MT/ha (van Peer, pers. comm., May 2012).[20]

What is clear is that outgrower schemes need a very dedicated team, excellent and knowledgeable hands-on management, and a strong research element. They also benefit from starting in highly suitable areas with sufficient grant money and/or investment to meet all the proof-of-concept training and transaction needs. One mature project that may succeed in becoming self-sustaining is the 'DI Oils outgrowers scheme' in Zambia.[21]

Outgrowers case study D1 Oils Zambia.

D1 Oils, Zambia grew out of DI Oils, Plc and will soon become a stand-alone company that will incorporate intercropping into its business model. Investor or grant money is needed to turn the proof of concept into a socially, economically and environmentally sustainable business. The strength of this project is that it grew from all of DI Oils experience, especially in Madagascar, and has the benefit of over US$ 15 million in research. The initial overly ambitious and unsuccessful out-grower programme instigated 6 years ago was downscaled to a realistic, proof-of-concept operation in Zambia's Eastern Province: it now entails 5 one-hectare training farms that demonstrate good and bad practices, 75 demo farms, 17 nurseries, and this season it is scaling up to about 500 farmers planting 400 trees each. The results are looking positive and they need another 1-2 seasons to prove that the model works for all stakeholders (Ross 2011). The project, if successful, has grown out of a high degree of sunk costs and research and a very intensive training and support approach over the last 5-6 years.

D1 Oils 2011

[20] Results and much information is available on www.jatropha.pro
[21] Like DI Oils, this project may soon change its name.

Table 21. Main activities achieved by the DI Oils Outgrower scheme in Zambia

	Main activities achieved
1	Area suitability maps developed
2	Extensive agronomy and operational knowledge compiled into a detailed jatropha Curcas extension manual detailing standard operating procedures
3	Detailed crop and activity calendars and nursery and planting guidelines for farmers produced
4	Quality of the results on the ground improved by careful farmer selection (land suitable for jatropha, sufficient labour and land) restriction of the no of trees planted in year 1 – 400, quality not quantity, integration of intercrops with jatropha strengthening of extension team
5	Best agronomy practices successfully transferred to jatropha growers via 5 training farms, 70 demonstration farms and 5 extension agents.
6	Market stimulated through active purchase of jatropha grain (250 MT to date
7	Trust developed with out-growers through honest consistent communication, h0nouring of promises, year round extension presence on the ground and fair and transparent pricing
8	Income generated in last two seasons (seedling production and sales, grain sales, buyers commissions, store rentals, transport 72000 $USD
9	Economics of crops for farmers and company are calculated
10	Business plan for scaling up to commercial scale developed

The €300 per hectare set-up benchmark.

In the first project steering committee, a benchmark of keeping the set-up and management costs to €300 per hectare was set. A few companies were able to give quite accurate set-up costs for a 10 hectare trial. Just as fertiliser made a key difference in the outgrower economics in Zambia, so it was fertiliser and manpower that made up most of the nursery set-up costs in one established farm. On this farm, located in Thika, the reported nursery costs amounted to €230 per hectare equivalent, compared with €13.6 equivalent reported in the optimal open conditions of Rea Vipingo in Kilifi. Rea's overall costs were further reduced in a second planting by dispensing with polybags. This may reflect their experience in cost-effectively replanting sisal.

Table 22. Comparative set up costs in different locations.

Set up costs: Euros per hectare			
Location	Nursery/ha	Planting out/ha	Total
Kilifi	13.6	135.2	148.8
Bungoma	77	134	211
Masindi		170.5	
Thika	230.1	141.4	371.5

Also in contrast to Thika, Lesiolo set up a 2.4 hectare provenance site with smallholders in Bungoma. With better temperatures than Thika, an open nursery system, and by using minimum inputs (such as farmyard manure) and labour, the overall set-up cost per hectare was still €371 (see details in Annex Seven).

In conclusion, choosing sites with potentially optimal agro-climatic conditions can be less costly to set up. One can imagine that on a larger scale, planting out by hand becomes expensive, and mechanised ripping and auguring, manure application, and direct seeding would be necessary. The main on-going costs at a small scale, aside from fertiliser, is manual weeding, and so most plantations are using a planting density of 3mx4m so that herbicide-spraying tractors can pass down the lines.

Hybrid systems with central farms and supported outgrower.

The project did not come across this system functioning effectively in East Africa. How it could work and what it could provide to communities is well represented in presentations made by Mike Lu, head of the Brazilian Jatropha Growers Association (Lu, 2009). Key to this model is not only a modern, well-equipped central farm with community facilities and modern processing plants, but also extensive use of mapping and mobile phone technology to solve problems for farmers in the field. Smallholders are encouraged to plant three rows of Jatropha around their plots and to use a 'Cartesian' four-crop rotation model within the boundaries.

Another interesting innovation reported by Embrapa was working with local banks to give farmers preferential loans to plant the right crops in the right place and the right time using the publicly available agro-climatic mapping GPS system. This had reportedly increased food productivity across a wide range of crops by 60%. This also supports the view of many within East Africa that focusing on increasing existing food yields in good agricultural areas is just as important as being wise about the location and impact of more intensive plantations.

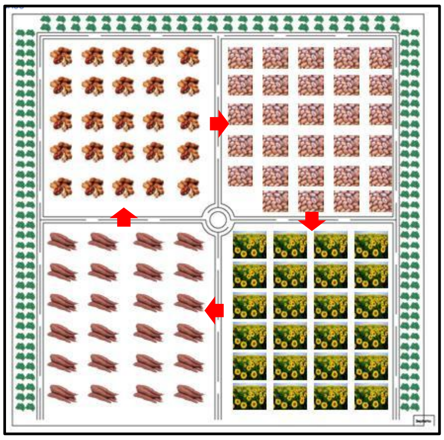

Figure 49. Crop rotation within Jatropha boundary hedges (Lu 2009)

Using SVO to replace electricity in a medium flower farm or sisal estate.

The project generated simplified models (see Annex Eight) that take the current energy costs per year of a medium-sized (25 hectare) flower farm in Kenya and a 1200 hectare sisal plantation and asks how many hectares of the fastest growing, highest yielding jatropha (6-7 kg per tree) and optimal SVO extraction rates to yield 2 MT of JSV oil per hectare, they would need to plant to replace their electricity use with existing standing back up generators. In both cases, with many capital and variable costs unaccounted for, the positive returns come after 7 years. Reduce the maximum oil yield per hectare to 1.5 tons and no return is seen within 10 years.

What is noticeable is that the largest capital outlay comes in year three, waiting for the yield to increase to 3-4 kg per tree to produce 1 ton of JSV oil per hectare. This has rarely happened in Africa and it is at this '3rd year into set-up' point that many companies with debts to service, have run out of finance and are either sold to new investors or go bankrupt and fold. So it is more likely that flower farms will continue to run on electricity and sisal plantations will invest in using sisal waste for biomass and biogas renewable energy production. One flower farm did set up a small jatropha plantation because in some circumstances they had no electricity and no diesel was available on the market. Then the daily losses due to no power may offset on-going running costs of investing in a small plantation as part of a suite of renewable energy supply and efficiencies. Even so, the kinds of high yields needed to make such a plantation cost-effective are yet to be seen in East Africa.

Setting up a large-scale plantation.

The above productivity and economic realities lead some to say that jatropha will only be commercially sustainable at larger scales, where economies of scale, carbon credits, and other supportive factors can come into play. Mitchell (2011) explores a 6,000 hectare plantation model that was highly sensitive to yield, harvesting costs, and oil extraction rates, and Pipal Ltd has generated two large-scale feasibility studies for Madagascar and Kenya. The case is yet to be proven in Africa. The many lessons in failure demonstrate that serious investors can lower the risks involved due to unclear and unpredictable regulatory, agronomic, and commercial environment by taking a number of actions:

1. Doing in-depth mapping and broad feasibility and local participatory studies of all aspects of the proposed project.

2. Choosing a change of use of an existing plantation or brown field site, and not a green field site in either legally, socially unclear or environmentally sensitive areas that are more prone to variable decision making at government level (as well as more international NGO criticism).
3. Companies should not base their forecast on higher value exports. Set up and production costs need to be covered by in-depth research into local market demand and costs and the profitable use of all by-products. This lowers the risk in case of either changes in developed world subsidies or subsidised quotas or sudden national policy changes banning export or making export untenable.
4. Buffering the success of the project by extremely tight financial and sequenced operational management of a set up and production plan that allows for unforeseen contingencies such as sudden fluctuations in agro-climatic condition, forex rates and costs and delays in project implementation.
5. Investing in cash crops, especially food, for financial return during the jatropha establishment period to buffer delays in expected harvest and lessen negative food for fuel advocacy.
6. Minimising the dependency on consistent local infrastructure by careful site selection and set-up.
7. Financing an emerging technology such as *Jatropha curcas* with extra equity to absorb the need for on-going varietal and good agricultural practices research. Setting up management teams with different expertise during the set up and establishment phases. This will entail either setting up a research oil testing laboratory, partnering closely with university or research consultancy platforms, trialing different harvesting equipment and techniques, pest and diseases management practices, as well as having extra agronomy and engineering capacity to monitor results closely as well as maintaining sophisticated financial auditing and costs modelling.

Most of the jatropha hype and unsustainable initial investment resulted from a lack of proven data on the agro-climatic conditions necessary to produce commercial yields, as well as the genetically stable varieties to produce the yields. It is now recognised that the plant needs at least 900-1000mm of rain, with at least 700mm spread evenly over the first five months of growth. Without huge increases in current yield potentials, irrigation can currently be considered uncommercial on any large scale. Sun Biofuels Mozambique is a plantation, which highlights that even in optimal agro-climatic conditions, extremely tight and responsive management is crucial to sustainable success. A team needs knowledge of the type and timing of fertilizer/hormone application and a deep understanding of integrated pest control systems, all of which is still emerging.

Section Seven: Markets

Local activities and markets.

As there is no substantial production of jatropha in Uganda, Tanzania or Kenya, there is no commercial supply into local markets as such. In order to look at this sector in any depth, an investor would need to assume that the national markets are directly correlated to the costs of replacing kerosene for domestic use with jatropha pure vegetable oil, or trans-esterified biodiesel for standing generators and/or blended car fuel. There would be no problem selling Jatropha either as straight vegetable oil or biodiesel if it was price-competitive. At this point, East African governments are unlikely to provide any tax incentives or subsidies.

The only product of jatropha that has penetrated a niche market in Tanzania so far is jatropha soap. Jatropha seedlings, cuttings, seeds and oil transactions are still confined between seeds collectors, oil extractors and soap makers. Diligent and others have created a small local market around their activities. The current price of jatropha seed in Tanzania is about Tsh 250-300/kg. The price of the oil is roughly 1 Euro at the factory gate. The seed cake is mainly sold as briquettes for Tsh 200/kg (Van Peer, pers. comm., 2011). KAKUTE's jatropha soap is now sold in Dar es Salaam, Mwanza, Moshi and other major town centres in Tanzania. KAKUTE produces around 1000kg of soap per year and sells it in the form of pieces of 30 and 90 g each. Their revenues from the sale of soap are about Tsh 6 million (about US$ 6,000) (van Eijck, 2007, pp. 136-146). The export potential of jatropha soap from KAKUTE is emerging with products being sent to USA.

There is a trend that seed prices continue to go up due to the fact that Diligent is facing competition from an NGO buying seeds to produce oil and electricity (Energy & Water Social Investment Company (EWC). EWC is involved in electricity supply, biofuel production (by processing jatropha seeds), biogas production, and rural water supply, and will become engaged in processing drinkable bottled water. They are part of the OMASI structure, which includes Dosi Engiteng [5 milk processing units in Maasai land (Longido, Terrat, Naberera, Orkesumet and Same)]. The southern Kenyan and northern Tanzanian Maasai Steppes are potentially limiting areas for jatropha, as was shown in Manyara.

Global jatropha activity and markets.

The rise and fall of jatropha globally has been charted by many reports. What is clear is that those still deeply engaged in R&D and either plantation and/or hybrid and outgrower schemes are those who will do the long-haul leg work to turn a wild, unpredictable and quite needy plant into a commercial source of jet and engine fuel, fertilisers and animal feed, green charcoal, glycerin and medicinal soaps.

Crude *Jatropha curcas* oil is not openly traded. Reported sales value in 2010-2011 range from US$540-975 per tonne (Hardman, 2011). In October 2011, a biodiesel website reported US$885 per tonne. There are also different views on the drivers of the price. As a niche product to fulfil Green PR events, such as when airlines want to prove they can fly on bio-jetfuel, to fulfil quotas, or to cover penalties, it can command high prices. If it becomes more available as a blend or a partial replacement for heavy fuel oil and low sulphur targets, it will align more with fossil fuel prices.

Some experts argue the technical merits of crude jatropha oil means that it should maintain a higher price when used for certain products. However, unlike crude palm oil, it does not have the flexibility to cross into the food oil markets. At the same time, GM reports that the number of double bonds means that jatropha oil is actually too thick for superfine car fuel-injection systems and will have to undergo further (FCC) cracking before being used, again adding processing costs for regular road vehicle diesel blends It is for this reason that many large jatropha associations, such as ABBPM in Brazil, are aligning themselves with the airlines to create a biokerosene jet fuels market. This market has been spurred on by the passing in July 2011 of an ASTM specification of biokerosene jet fuel, allowing up to a 50% blend. Jatropha currently features as a key feedstock along with camelina, industrial waste and bioalgae.

Large high tech and very well resourced players are now enthusiastically entering into the market. The range of feedstocks is likely to increase rapidly to wood chips and other lingo-cellulosic and waste products.

Unless East Africa can leapfrog into their own domestic high-end technology processing plants, the demand for African-grown jatropha CJO for bio-jetfuel may be short lived, as waste feedstocks may become economically available and subsidised in developed countries. These kinds of projections are mirrored by the estimated growth of different types of biofuels in the US market.

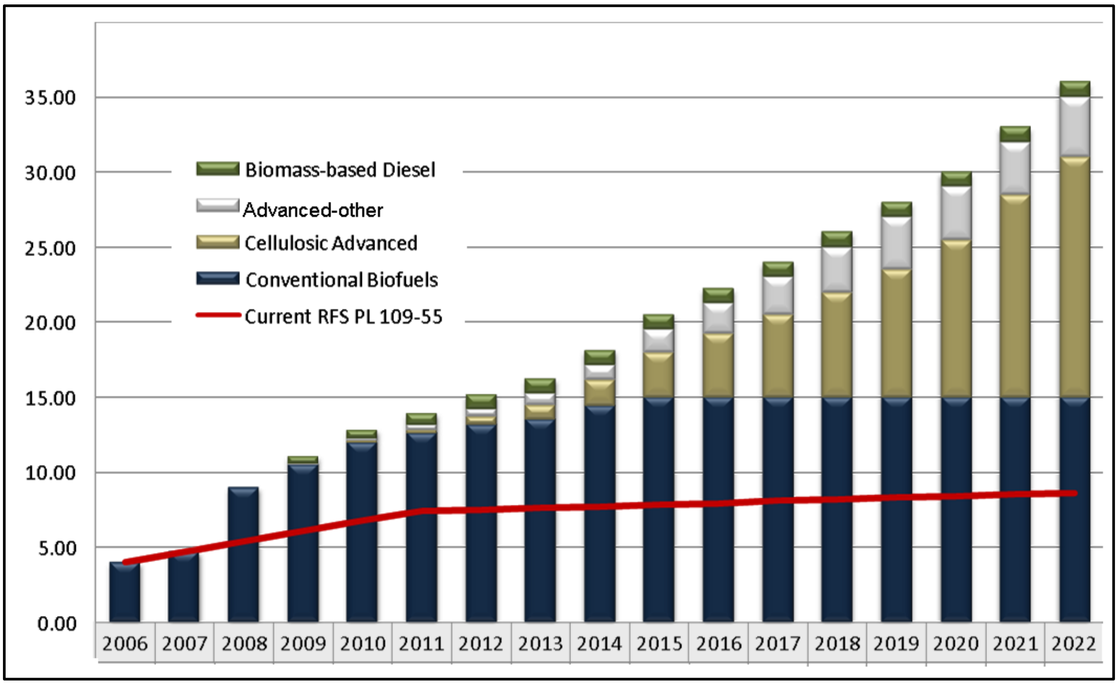

Figure 50. Source: Candace Wheeler General Motors: presentation at the World Biofuels Summit. Barcelona Jan 2011

However, all of these are projections and, as previous anticipated yields of jatropha have shown, projections and future reality do not necessarily align.

As far as financing a jatropha project in 2012, the majority of jatropha-focused businesses have experienced a decline in capital value since the 2007-08 years of hype. This seems to have been exacerbated by premature investment in processing plants. Large-scale investments in potentially limiting or fair agro-climatic conditions have also not fared well. Some bilateral renewable energy grant funds that cover East Africa have specifically excluded any jatropha projects (e.g., EEES). Nevertheless, Sun Biofuels, Mozambique and some other strong African projects have found new investors who expect to take the jatropha projects to commercially viability.

The initial equity investment lost through Sun Biofuel's foray into Ethiopia on poor soils, before relocating to Tanzania and a better location in Ethiopia is probably a major cause of the principal shareholding changes in 2011, ESV reportedly changed hands without appearing to incur capital losses (Hardman, 2011). Sun Biofuel's teams in Tanzania and Mozambique have been the frontrunners in professional planters developing and slowly scaling plantations in suitable growing locations. It is lessons from these emerging ventures, along with serious outgrower schemes, and maybe very different planting models with new hybrids, that may yet find a way to make a commercial jatropha plantation profitable in Africa. Given the on-going large-scale research in Brazil and India, as well as the recent upsurge of interest in jatropha in Southeast Asia (Philippines, Thailand and Indonesia) and in China, a critical mass of examples of using *Jatropha curcas* as a commercially viable feedstock for biofuels may still emerge.

Reference list

Abdelgadir H.A., Johnson S., Van Staden J., (2009) 'Promoting branching of a potential biofuel crop *Jatropha curcas L.*by foliar application of plant growth regulators'. Plant Growth Regulation 58 (3): 287–295

Attaya A.S., Geelen D., Belal A. E. H., (2012) 'Progress in Jatropha Curcas Tissue Culture,' American-Eurasian Journal of Sustainable Agriculture, 6(1): 6-13, ISSN 1995-0748,

Andreasson K., and Richard M., (2011) 'A sustainable miracle? Determining the socio-economic sustainability of small scale jatropha cultivation in the Eastern province of Zambia' Arbetsrapporteur Kulturgeografiska institutionen Nr 783 Uppsala Universitet ISSN 0283-622X

Basha S.D., Francis G., Makkar H.P.S., Becker K., Sujatha M., (2009) 'A comparative study of biochemical traits and molecular markers for assessment of genetic relationships between Jatropha curcas L. germplasm from different countries.' Plant Science

Bationo A., Nandwa S.M., Kimetu J.M., Kinyangi J.M., Bado B.V., Lompo F., Kimani S., Kihanda F., and Koala S.,(Nov 2004). 'Sustainable crop–livestock production in West Africa; Sustainable intensification of crop–livestock systems through manure management in eastern and western Africa, Lessons learned and emerging research opportunities.'

Baumgart S., (2007). Jatropha Cultivation Belize. Presentation made at Expert seminar on 'Jatropha curcas L. Agronomy and genetics.' Wageningen, The Netherlands, FACT Foundation and reported on by Jongscahaap. (2008)

Belewu M.A., Elewu M.A., Adekola F.A., Adebayo G.B., Ameen O.M., Muhammed N.O., Olaniyan A.M., Adekola O.F., and Musa A.K., (2010). 'Physico-chemical characteristics of oil and biodiesel from Nigerian and Indian *Jatropha Curcas* seeds.' Int. J. Biol. Chem. Sci. 4(2): 524-529, Available online at http://ajol.info/index.php/ijbcs

Behera S.K., Srivastava P., Tripathi R., Singh J.P., Singh N., (2010) 'Evaluation of plant performance of Jatropha Curcas L. under different agro-practices for optimizing biomass.' A case study,' In: Biomass and Bioenergy 34, Pp.30-41.Available at http://www.elsevier.com/locate/biombioe

Berryman A.A., (2003). 'On principles, laws and theory in population ecology.' Oikos, 103, 695-701.

Briggs John, (1992). Fractals: 'The patterns of chaos; discovering a new aesthetic of art, science and nature.' Thames and Hudson Ltd, London.

Brittaine R., and Lutaladio N., (2010), 'Jatropha: A Smallholder Bioenergy Crop, The Potential for Pro-Poor Development Integrated Crop Management.' Rome, FAO 8.

Boestler F., (2010) 'The potential for the Production of Bioenergy for Lighting and Cooking Using Jatropha (Jatropha Curcas L. Euphorbiaceae) by Small Scale Farmers on the Kenyan Coast.' GRIN Verlag. Available http://darwin.bth.rwth-aachen.de/opus3/volltexte/2010/3411/pdf/3411.pdf Last accessed 23rd May 2012

Chang-wei L., Kun L., You C., Yong-yu S., (2007) 'Floral display and breeding system of *Jatropha curcas* L.' Research article for China

Chao Z. et al., (2012) ‘ Jatropha curcas curcin genes, tissue-specific promoters and generation of curcin-deficient transgenic jatropha plants’ Patent application last downloaded at http://www.faqs.org/patents/app/20120073018#b May 21 2012

Davison Canney S., (2011). ‘Liquid Biofuels Strategies and Policies in selected African Countries.’ Prepared for PISCES by Practical Action Regional Office for Eastern Africa in collaboration with Pipal Ltd

DECON/REAC (2008) ‘Updating of the Rural Electrification Master Plan.’ Final report under MFA contract- Provisional master plan – Volume 3: Background and technical studies. Annex 3.2.1.: Assessment of Renewable Energy Options. Ministry of Energy Kenya, Ministry of foreign Affairs Finland.

Dhillon K.S., (9-10June2006) ‘Jatropha Cultivation in Punjab, Biodiesel Conference Towards Energy Independence-Focus Jatropha.’ Papers presented at the conference Rashtrapati Nilaym, Bolaram, Hyderabad.

Eberhard A.,Vivien F., Garmendiaa C.B., Ouedraogo F., Camos D., and Shkaratan M., (2008), ‘Underpowered: The State of the Power Sector in Sub-Saharan Africa.’ Background paper 6, Africa Infracture Country Diagnostic, World Bank

FACT Foundation (2010) ‘Jatropha handbook; from cultivation to application’ Available at http://www.snvworld.org/sites/www.snvworld.org/files/publications/fact_foundation_jatropha .Last accessed 22nd May 2012

Friends of the Earth, (June 2010), ‘Africa; up for grabs: the scale and impact of land grabbing for agro fuels.’ Report, Available at http://www.crepeweb.net/wp-content/uploads/2010/11/crepe-wp1-final-report.pdf Last accessed 22nd May 2012

Gachimbi L., (2002) ‘Technical Report of Soil Survey and Sampling – Embu-Meru districts’ Kenya working papers 9 & 10 LUCID’s Land Use Change Analysis as an approach for Investigating Biodiversity loss and land degredation project. ILRI UNEP DGEF

Geply O.A., Baiyewu R.A., Adegoke I.A., Ayodel O.O., and Ademola I.T., (2011), ‘Effect of different pot sizes and growth media on the agronomic performance of Jatropha Curcas.’ Pakistan Journal of Nutrion 10, pg. 952-954, Asian Network for Scientific Information

Ginwal H.S., Phartyal S.S., Rawat P.S., Srivastava R.L., (10th May 2005). ‘Seed Source Variation in Morphology, Germination and Seedling Growth of *Jatropha curcas* Linn. In: Central India.’

Giannini A., Biasutti M., Held I.M., Sobel A., (2008), ‘A global perspective on African Climate.’ Climatic Change Vol. 90 Pages 359 – 383

Gordon-Maclean A; Laizer J., Harrison P., and Shemdoe R., (2009), Biofuel Industry Study Tanzania: An Assessment of the Current Situation, World wildlife Fund for Nature.

GTZ (2009), ‘Jatropha Reality Check’; A Field assessment of the agronomic and economic viability of Jatropha and other oilseed crops in Kenya, Deutsche Gesellschaft fur, Available at http://www.worldagroforestry.org/downloads/publications/PDFs/B16599.pdf Last accessed 22May 2012

Harinder M., Francis G., and Becker K. J., Sci. Food Agric. 88:1542–1548 (2008).

Hawkins D., and Chen (2011), ‘Plant with a Bad name.’ Hardman &Co. Leaders in Corporate Research

Herrera J.M., Ayala A.L.M., Makkar H., Francis G., Becker K., (2010) 'Agro climatic Conditions, Chemical and Nutritional Characterization of Different Provenances of Jatropha.' European Journal of Scientific Research, ISSN 1450-216X Vol.39 No.3 (2010), pp.396-407 Available at http://www.eurojournals.com/ejsr.htm

Islam A.K.M., Anuar N., Yaakob Z., Osman M., (2011). 'Heterosis for Seed Yield and its Components in Jatropha (*Jatropha Curcas L*)' International Journal of Plant Breeding, Vol.5 No 2; 74-79

Jeger MJ., Pautasso M., Holdenrieder O., Shaw M.W., (2007) 'Modelling disease spread and control in networks: implications for plant sciences.' New Phytol, Vol: 174, Pages: 279-297, ISSN: 0028-646X

Jeger M., da Clara MI., Phillips A., Walters D., Boonekamp P., (2012), Foreword: Integrated plant disease management, EUROPEAN JOURNAL OF PLANT PATHOLOGY, Vol:133, Pages:1-1, ISSN:0929-1873

Jones N. and Miller J.H., (1993) 'Jatropha Curcas a Multipurpose Species for Problematic Sites.' The World Bank, Washington D.C

Jongschaap R.E.E., (2008) 'Presentation on A to Z of Jatropha Curcas L, Claims and Facts on Jatropha Curcas L.' Plant Research International June 2009, Wageningen University Netherlands

Jongschaap R.E.E., Corre W.J., Bindraban D.S., and Brandenburg W.A., (Oct 2007) 'Claims and Facts on Jatropha Curcas L., Global Jatropha Curcas Evaluation, Breeding and Propagation Programme,' Plant Research International BV Report 158, Laren, the Netherlands. *Available online:* www.pri.wur.nl

Kaur K., Dhillon G.P.S., and Gill RIS, (2011) 'Floral biology and breeding system of Jatropha Curcas in North-Western India,' Journal of Tropical Forest Science 23(1): 4-9, Forest Research Institute, Malaysia

Kaushik, N., J. C. Kaushik, S. Kumar (2003) 'Response of Jatropha curcas to seed size and growing medium.' Journal of Non-Timber Forest Products 10:40-2

Kaushik N., K. Kumar, S. Kumar and S. Roy (2007) 'Genetic variability and divergence studies in seed traits and oil content of Jatropha (Jatropha curcas L.) accessions.' Biomass and Bioenergy 31:497-502.

Khetri, Biodiesel Programme-NEDFi's initiative, Presentation at R&D Centre

Kiwele P.M., (2009) 'Status of the Tanzania Biofuels Policy' Presentation at Stakeholders meeting organized by Policy Innovation System for Clean Energy Security,) PISCES Dar es Salaam

Liu X., Ye M., Pu B., and Tang Z., (2012) 'Risk management for jatropha curcas based biodiesel industry of Panzhihua Prefecture in Southwest China' Renewable and Sustainable Energy Reviews (16).Available at www.elsevier.com/locate/rser

Liu K., Kenan L., Qiliang Y., Zhenyang G.E., Liu X. L., (2012)' Simulation of *Jatropha curcas* L. Root in Response to Water Stress based on 3D Visualization,' Procedia. Engineering 28,403-408, International Conference on Modern Hydraulic Engineering, Elseiver Ltd., Available online at www.elsevier.com/locate/procedia

Loo V. E.N., Jongschaap R.E.E., Montes Osorio L.R., and Azurdia C., (2008) 'Jatropha curcas L.: Genetic diversity and breeding.' Temasek Life Sciences Laboratory, www.jatrophacongress.org. Jatropha International Congress, 17-18 December 2008, Singapore

Loos and Kagiso T., (2008) 'Socio-economic impact of a Jatropha project on smallholder farmers in Mpanda, Tanzania' Case study of a public-private partnership project in Tanzania. Msc Thesis, University of Hohenheim, Institute for Agricultural Economics and Social Sciences, Stuttgart, Germany

Loos T.K., Wahl J N., and Zeller M., (2009) Jatropha Production in Tanzania: Smallholders struggle to Profit'. Poster for Universitat Hohenhiem Department of Agricultural economics and social sciences in the tropics and sub tropics

Lu M., (2009) 'ABPPM' associação brasileira dos produtores de pinhão manso' Presentation made at the World Biofuels Markets, March 16-18th 2010 Amsterdam, Netherlands

Lu M., (2010) 'ABPPM' associação brasileira dos produtores de pinhão manso' Presentation made at the World Biofuels Markets, March 15-17th 2010 Amsterdam, Netherlands

Lyon B., D. G. DeWitt (2012), 'A recent and abrupt decline in the East African long rains' *Geophys. Res. Lett.*, *39*, L02702, doi: 10.1029/2011GL050337.

Maes W.H., Achten W.M.J., Reubens B., Raes D., Samson R., Muys B., (2009) 'Plant–water relationships and growth strategies of Jatropha curcas L. seedlings under different levels of drought stress.' Journal of Arid Environment (73), Available at www.elsevier.com/locate/jaridenv

Maitima, J.M., Mugatha S.M., Reid R.S., Gachimbi L.N., Majule A., Lyaruu H., Pomery D., Mathai S., and Mugis S., (2009) 'The linkages between land use change, land degradation and biodiversity across East Africa.' African Journal of Environmental Science and Technology Vol. 3 (10), pp. 310-325. Research paper, Available online at http://www.academicjournals.org/AJEST

Makkar H.P.S., Aderibigbe A.O., Becker K., (1998). 'Comparative evaluation of non-toxic and toxic varieties of Jatropha curcas for chemical composition, digestibility, protein degradability and toxic factors' Food Chem. 62 207–215

Makkar H.P.S., Becker K., Schmook B., (1998) 'Edible provenances of Jatropha curcas from Quintana Roo state of Mexico and effect of roasting on antinutrient and toxic factors in seeds' Plant Foods Hum. Nutr. 52: 8:66-7931–36.

Makkar H.P.S., and Becker K., (1999) 'Nutritional studies on rats and fish (carp Cyprinus M Carpio) fed diets contained unheated and heated Jatropha curcas meal of a non-toxic provenance.' Plant foods for Human nitration 53:183-192.

Makkar H.P.S., and Becker K., (2009) '*Jatropha Curcas*, a promising crop for the generation of biodiesel and value-added co products' European Journal of Lipid science and Technology, Vol.111 Issue 8:773-787. DOI: 10.1002/ejlt.200800244

Manoharan, T., Ambika S., Natarajan N., and Senguttuvan K., (2006), 'Emerging pest status of Jatropha Curcas (L) in south India.' Ind. J. Agroforestry)

Martinez-Herrera J., Siddhuraju P., Francis G., Davile Ortiz G., Becker K., (2006) Chemical Composition, toxic/antimetabolite constituents, and effect of different treatments on their levels, in four provenances of Jatropha curcas L. from Mexico' Food Chem. 96: 80–89

McGahey D.J., (2008) 'Bioenergy and Pastoralism: challenging the wasteland myth. Dry net Report prepared by SOS Sahel International UK for the UNCCD CRIC V11 Special side event on the wastelands/pastoralism.

Messemaker L., (2008). 'The Green Myth? Assessment of the Jatropha value chain and it's potential for pro-poor biofuel development in Northern Tanzania.' Faculty of Geosciences, Utrecht University, The Netherlands

Mohan N., Nikdad S., Singh G., et al (2011) 'Studies on seed germination and embryo culture of *Jatropha Curcas* L under in vitro conditions' Biotechnol.Bioinfo. Bioeng. Vol. 1 No 2:187-194

Ministry of Energy (2011) 'National Biofuel Policy and Strategy', Draft national biofuel policy session paper, final draft 2 for circulation Nov, 2010

Ministry of Energy (2010) 'Strategy for developing the biodiesel industry in Kenya for 2010 – 2015,' Renewable Energy Department, Government of Kenya Printer

Ministry of Energy and Minerals (2008) 'Guidelines for sustainable development of liquid biofuels and co-generation in Tanzania'

Misra M., and Misra A.N., (2010) 'Jatropha: The Biodiesel Plant Biology, Tissue Culture and Genetic transformation.' A Review Int.J.Pure Appl.Sci.Techno., Vol. 1 No1:11-24

Mitchell D., (2010) 'Biofuels in Africa: Opportunities, Prospects, and Challenges.' The World Bank, Washington D.C, Available at http://africaknowledgelab.worldbank.org/akl/node/67

Mogaka Moraa V., Iiyama M., Nzuma J., Munster C., Mbatia O.L.E. Hunsberger C., (2009), 'Food or Jatropha curcas for biodiesel production? A cost benefit analysis in Kwale District.' DSA paper

Mogaka V. M., IIyama M., O.L.E, Nzuma J., (2010) 'Reality or Romanticism? Potential of Jatropha to solve energy crisis and improve livelihoods.' Poster presented at Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists association of South Africa) AESA conference Cape Town South Africa

Mohan N., Nikdad S., Singh G., (2011) '*Jatropha curcas* L. under *in vitro* conditions.' Research Article, Biotechnol. Bioinf. Bioeng, 1(2):187-194, Society for Applied Biotechnology, India.

Mortimer N.D., (2011) 'Life cycle assessment of Refined Vegetable oil and biodiesel from Jatropha Grown in Dakatcha woodlands of Kenya' North Energy Associates Limited. www.northenergy.co.uk

Muok B.O., Nyabenge M., Ouma B.O., Esilaba A.O., Nandokha T., and Owuor B., (2010) 'Environmental Suitability and Agro-environmental Zoning of Kenya for Biofuel Production.'ACTS, PISCES and UNEP

Nyathi P., Kimani SK., Jama B., Mapfumo P., Murwira, H.K., Okalebo J.K., Bationo A., (2003) 'Soil fertility management in semi-arid areas of East and Southern Africa.' In (ed.) Gichuru M.P., Bationo A., Bekunda M.A., Goma H.L., Mafongonya P.L., Mugendi D.N., Murwira H.M., Nandwa S.M., Nyathi P., and Swift M.J., 'Soil Fertility Management in Africa: A Regional Perspective.' TSBF-CIAT, Academy Science Publishers (ASP) Nairobi

Nylin S., (2001). Life history perspective on pest insects: what's the use? Austral ecology. 26, 507-517.

Otieno B.A., Njenga F., Mwangi L., Oballa P.O., (2011) 'An Integrated approach to managing insect pests in plantations of jatropha Curcas.' A project report for the DEGJSP Support Programme

Ouattara B., Diedhiou I., Ndir K.N., Diouf D., Akpo L.E., (2011) 'Effect of water regimes and pre-sowing treatments on seeds germination of different provenances of Jatropha curcas L. in Senegal'. International Journal of Science and Advanced Technology (ISSN 2221-8386*)* Volume 1 No 9

Ovando-Medina I., García F.E., Núñez-Farfán J., Salvador-Figueroa M., (2009), 'Does Biodiesel from *Jatropha Curcas* represent a sustainable alternative energy source?' Sustainability *1(4)* 1035-1041 http://dx.doi.org/10.3390/su1041035

Ovando Medina I., García F.E., Farfán J.N., and Figueroa M.S., (2011) 'Genetic variation in Mexican Jatropha Curcas L. estimated with seed oil fatty acids' Journal of Oleo Science 60(6) 301-311

Ovando Medina I., García F.E., Farfán J.N., Figueroa M.S., (2011) 'State of the art of genetic diversity research in *Jatropha Curcas.'* Scientific Research and Essays Vol.68, 1709-1719 ISSN 1992-2248

Ovando-Medina I., Sánchez-Gutiérrez A., Adriano-Anaya L., Espinosa-Garcia F., Núñez-Farfán J., Salvador-Figueroa M., (2011) 'Genetic diversity in *Jatropha Curcas* populations in the State of Chaipas Mexico.' Diversity 3(4) 641-569 http://dx.doi.org/10.3390/d3040641

Pan B-Z., Xu Z-F., (2011). 'Benzyladenine treatments significantly increase the seed yield of the biofuel plant *Jatropha Cur*cas. J.' Plant Growth Regulation Vol. 30 No 2: 166-174 DOI 10.1007/s00344-010-9179-3

Paz Ander and Vissers P (Nov 2010). 'Greenhouse gas calculations Jatropha value chain.' Sun Biofuels Mozambique, Partners Innovation

Peer Ab van (2010). 'Growing Jatropha; including propagation methods for Jatropha Curcas and production and use of Jatropha products'. Available at www.jatropha.pro

Popluechai S., Breviario D., Mulpuri S., Makkar H.P.S., Raorane M., Reddy A.R., Palchetti E., Gatehouse A.M.R., Syers J. K., O' Donnell A.G.O., Kohli A., (2009) 'Narrow genetic and apparent phenetic diversity in Jatropha curcas: initial success with generating low phorbol ester interspecific hybrids.' Nature preceedings

Popluechai S., (2010). 'Molecular characteristaion of *Jatropha curcas*, towards an understanding of its potential as a non-edible oilseed based source of biodiesel.' Thesis submitted for PhD Faculty of SAgE Newcastle University UK.

Pranesh K.J., Gururaja M.R., Sowmya H.C., Savithramma D.L., Naveen N.L., (2010) 'Studies on floral display and mode of reproduction in Jatropha (Jatropha Curcas L.)' Research article, Electronic Journal of Plant Breeding 1(4):832-838.

Rafii M.Y., Arolu I.W., Omar M.H.A., and Latif M.A., (2011) 'Genetic variation and heritability estimation in *Jatropha curcas* L. population for seed yield and vegetative traits' Journal of Medicinal Plants Research Vol. 6 No11: 2178-2183.

Rajaona A., Bruek H., Asch F., 'Description of the spatial arrangement of Jatropha Curcas L. root system.' A case study from Madagascar, Universitat Hohehiem, Available at https://jatropha-madagaskar.uni-hohenheim.de

Rao, V.R., (2006). 'The Jatropha Hype: Promise and Performance.' In: Singh, B., Swaminathan R., Ponraj, V. (eds), 2006. Biodiesel Conference Towards Energy Independence – Focus on Jatropha. Rashtrapati Nilaym, Bolaram, Hyderabad.

Rao, G. R., Korwar G.R., Shanker A.K., Ramakrishna Y.S., (2008), 'Genetic associations, variability and diversity in seed characters, growth, reproductive phenology and yield in *Jatropha curcas* (L.) accessions.' Trees 22:697-709

Ross S. (2011) 'Growing Energy Solutions' Di Oils.' Presentation on D1 Oils outgrowers scheme in Zambia (sent through email)

Rossi A., and Lambrou Y., (2008) 'Gender and equity issues in liquid biofuels production', minimizing the risks and maximizing the opportunities' Food and Agriculture Organisation of the United Nations, Rome

Rug M., and Ruppel A.,(2000) 'Toxic activities of the plant Jatropha curcas against intermediate snail hosts and larvae of Schitosomes' Tropical Medicine and International Health 5 (6) 423-430.

Saturnino M.H., Pacheco D.D., Kakida J., Tominanga N., Goncalves P.N., (2005) ' Cultura do Pinhao-Manso (Jatropha Curcas L.).' In: Informe Agropecuario: Producao de oleaginosa para biodiesel. EPAMIG-CTNM (Ed.). Belo Horizonte, Brazil.

Sattari S.Z., Bouwman A.F., Giller K.E., van Ittersum M.K., (2012). 'Residual soil phosphorus as the missing piece in the global phosphorus crisis puzzle' Proceedings of the National Academy of Sciences of the USA, March 16th http://www.pnas.org/cgi/doi/10.1073/pnas.1113675109

Scharschmidt A. S., (2010). 'Macro-economic impacts of large scale Jatropha cultivation and biodiesel production in Tanzania.' Master Thesis. School of Economics Utrecht University

Silip J.J., Tambunan A.H., Hambali E., Sutrisno and Surahman M., (2011) 'High accumulation of lipids during off-tree ripening and senescence in *Jatrophacurcas* Linn Luanti accession kernels' America Journal of Scientific and Industrial Research. ISSN: 2153-649X, doi:10.5251/ajsir.2011.2.2.246.250

Silip J.J., Tambunan A.H., Hambali E., Sutrisno and Surahman M., (2010), 'Extracted Oil Yield and Biomass Changes during on-Tree Maturation, Ripening and Senescence of Jatropha Curcas Linn Fruits.' European Journal of Scientific Research Vol.44 No.4:602-609. ISSN 1450-216X.

Srinophakun P., Saimaneerat A., Sooksathan I., Visarathanon N/. Malapian S., Charernsom K/. Chongrattanameteekul W., (2011) 'Integrated research on Jatropha curcas Plantation Management,' Paper presented at the World renewable energy congress. Linkoping Sweden 8-13 May 2011.

Sujatha M., Reddy T.P., Mahasi M.J., (2008) 'Role of biotechnological interventions in the improvement of castor (*Ricinus communis* L.) and *Jatropha curcas* L., Biotechnology' Advances Vol. 26: 424-435, doi:10.1016/j.biotechadv.2008.05.004

Sulle E., and Nelson F., (2009) 'Biofuels, Land Access and rural livelihoods in Tanzania.' IIED London, ISBN: 978-1-84369-749-7

Suriharn B., Sanitchon J., Songsri P., Kesmala T., (2011) 'Effects of Pruning Levels and Fertilizer Rates on Yield of Physic Nut.' (Jatropha Curcas L.), Asian Journal of Plant Sciences, 10: 52-59.DOI: 10.3923/ajps.2011.52.59.

Tadakittisarn S., Janchai P., Vaithanomsat P., and Apiwatanapiwat W., (2011) 'Effect of Ripening Stage and Temperature on Free Fatty Acid Content of *Jatropha curcas* Oil During Storage.' Kasetsart J. (Nat. Sci.) 45: 275 - 283

Tambunan A.H., Situmorang J.P., Silip J.J., Joelianingsih A., and Araki T., (2012), 'Yield and physicochemical properties of mechanically extracted crude Jatropha Curcas L oil.' Biomass and Bioenergy 43:12-17.

Temu A.K., (2008) 'Large Scale biofuel Production in Tanzania- Feasibility', Presentation CoET, UDSM

The Insolvency Service (2012) 'International bio-diesel companies, Greenleaf Global, closed down following Government investigation'

Theting H., and Brekke B., (2010) 'Land Investments or Land grab? A critical view from Tanzania and Mozambique.' Spire, Available at www.spireorg.no

Thornton P.K., Jones P.G., Owinyo T.M., Kruska R.L., Herrero M., Kristjanson P., Notenbaert A., Bekele N., and Omolo A., with contributions from Orindi V., Ochieng A., Bhadwal S., Anantram K., Nair S., Kumar V., and Kulkar U., (2006), 'Mapping Climate Vulnerability and Poverty in Africa'. Report to the Department for International Development, ILRI, PO Box 30709, Nairobi 00100, Kenya.

Titapiwatanakun B., Sooksathan I., Punsuvon V., (2012, 'Prospect of deoiled *Jatropha curcas* seedcake as fertilizer for Vegetable Crops.' A case study, Journal of Agricultural Science Vol. 4 No 3: 211-226

Tomomatsu Y., Swallow B., (2007) 'Jatropha Curcas Biodiesel Production in Kenya: Economics and Potential Value Chain Development for Smallholder Farmers.' Working Paper 54, World Agroforestry Centre, Nairobi.

Townsend A., Porder S., (2012. 'Agricultural legacies, food production and it's environmental consequences.' PNAS commentary Vol 109, No 16 5917-5918.

Trabucco A., Achten W., Boewe C., Aerts R., Orshoevn J.V., Norgroves L., and Muys B., (2010) 'Global mapping of Jatropha Curcas yield based on response of fitness to present and future climate' GCB Bioenergy Vol. 2:131–151 doi:10.11111/j.1757-1707.2010.01049.X

Valdes-Rodriguez O.A., Sanchez O.S., Vazquez A.P., and Bello R.R., (2011 'Soil texture effects on the development of Jatropha seedlings- Mexican variety 'pinon manso.' Biomass and bioenergy 35, pages 3529-3536, Available at http://www.elsevier.com/locate/biombioe

vanEijck, J., and Romijn H.,(2008) 'Prospects for Jatropha Biofuels in Tanzania: An analysis for Strategic Niche Management'. Energy Policy Vol. 36 Issue 1:311-325

vanEijck J., et al (2010) 'Jatropha assessment' agronomy, socio- economic issues and ecology.' NL agency, Ministry of economic affairs, agriculture and innovation

Volkaert V., (2008) 'Jatropha Curcas: beyond the myth of the miracle crop'. Presentation first delivered at Africa Biofuels Conference Midrand South Africa.

Wahl N., Jamnadass R., Baur H., Munster C., and Iiyama M., (2009) 'Economic viability of Jatropha curcas L. plantations in Northern Tanzania – Assessing farmers prospects via cost-benefit analysis.' ICRAF, Working Paper no. 97, Nairobi, World Agroforestry Centre

Wekesa L., Ngethe R., Wamahui P., Esilaba A., and Muturi G., (2010) 'Analysing the economic potential of Jatropha in Kenya.' E. Afr. Agr. For. J. 76: (1)

Wijaya A., Susantidian, Harun M.U., Hawalid. H., (2009 'Flower Characteristics and the Yield of Jatropha (*Jatropha Curcas* L.) Accessions' HAYATI Journal of Biosciences, Vol. 16, No. 4:123-126.

Wu J., Liu Y., Tang L., Zhang F., and Chen F., (2011) 'A study on structural features in early flower development of Jatropha Curcas L. and the classification of its inflorescences.' African Journal of Agricultural Research Vol. 6(2) 275-284

Yang C.Y., Fang Z., Li B., Long Yun-feng (2012) 'Review and prospects of Jatropha biodiesel industry in China' Renewable and Sustainable Energy Reviews 16, 2178-2190

Yang C-Y., Deng X., Fang Z., Peng D_P., (2010) ' Selection of high –oil yield sources of Jatropha Curcas L for biodiesel production.' Biofuels Vol. 1 No 5:705-717

Yang M., Liu Y., Liu Y., Chen H., Chen F., and Shen S.H., (2009 'Proteomic Analysis of Oil Mobilization in Seed Germination and Post germination Development of *Jatropha Curcas*.' Journal of Proteome Research, 8 (3), 1441-1451.Published the American Chemical Society, Washington, DC

Ye M., Li C., Francis G., Makkar H.P.S., (2009) 'Current situation and prospects of Jatropha Curcas as a multipurpose tree in China.' Agroforest Syst 76: 487-497 DOI 10.1007/s10457-009-9226-x

Yin L., T.X. Hu, Y.A. Lui, S.F. Yao, J. Ma, W.T. Liu and C. He (2010), 'Effect of drought on photosynthetic characteristics and growth of Jatropha curcas seedlings under different nitrogen levels.' Ying Yong Sheng Tai Xue Bao, 21: 569-576.

Yong J.W.H., Y.F. Ng, S.N. Tan and A.Y.L. Chew (2010) 'Effect of fertilizer application on photosynthesis and oil yield of Jatropha Curcas L.' Photosynthetica 48: 208-218.

Zaidman B. Z., Ghanim M., Vaknin Y., (2010), 'Effect of seed weight on seed vigour and, early seed growth of Jatropha Curcas, a biodiesel plant.' Seed Sci and Technol., 38, 758 - 767

Zhang Z., Zhou S., Zou T., Chen G., (2008) 'Fractal scale-free networks resistant to disease spread' Journal of Statistical Mechanics Issue 9 http://dx.doi.org/10.1088/1742-5468/2008/09/P09008.

Zong H., S. Wang, C. Ouyang, X. Deng, L. Li, J. Li and F. Chen, 2010. *Agrobacterium*-mediated transformation of *Jatropha curcas* young leaf explants with lateral shoot-inducing factor (*LIF*). Int. J. Agric. Biol., 12: 891–896