Lessons Learned:
Jatropha for local development

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2 INTRODUCTION

This document gives a summary of lessons learned from the first three Jatropha pilot projects from FACT, which took place in Mali, Mozambique and Honduras, from 2007-2009 (with Mozambique being until 2010).

The findings presented here are the main findings from many experiments, tests and observations carried out in the field by the three projects. This document is complementary to other documents published by FACT, including the FACT Jatropha Handbook, 2nd edition 2009, and the End reports of the three pilot projects.

The three pilot projects focused on production of biofuels by poor and subsistence farmers to increase their income and to substitute fossil fuel used locally with biofuel, in contrast to large-scale commercial plantations focused on export markets which have been the goal of other projects. The study "Jatropha Assessment" by Agentshap NL gives information on this latter type of projects, in addition to those with a target group similar to that of the FACT projects.

We hope this document is useful for:

- **Practitioners:** to get practical recommendations under which conditions Jatropha can work, and solutions to many practical problems. Due to the brevity of this publication, technical solutions are only described in brief, but references to detailed publications are provided.

- **Project planners & donors:** to see how this new production chain fares on the ground and what to consider in future projects. This report can hopefully give a clearer picture of points at which planners & donors have been too optimistic in the past and where there is still potential for significant impact.

- **Researchers:** to see what areas need attention on the ground. It was for instance found that a focus on small-scale farming systems and local use raises other research questions than those prioritised by commercial producers and the biofuel industry.

Each chapter covers a main topic that came up in the projects. A brief summary covers the main lessons learned for each topic. This is followed by a shortlist of all the major lessons, allowing for a quick overview. The rest of the chapter elaborates the issues more.

The focus of this report is lessons learned from the three pilot projects, but supportive evidence from other projects is also used to provide important contextual information to better understand findings and recommendations emerging from the three projects. When findings from the three pilot projects refute general findings reported in the literature, this is noted; for example, the general opinion in many studies is that Jatropha endangers food security. However, findings presented here indicate that this is not necessarily so.

A list of references is provided at the end of the publication. In addition, the projects in Honduras[1] and Mozambique[2] have published websites presenting the majority of documents

[1] http://gotaverde.org/en_new_portal/
[2] https://sites.google.com/site/mozambiqueJatropha

on the projects. Finally, experiences from the three projects have also been used in several publications by the FACT Foundation and can be found on its website[3].

If you need further information and cannot find it on the websites, please feel free to contact the FACT Foundation or the authors directly.

[3] http://www.fact-foundation.com/

3 INTRODUCTION TO THE PROJECTS

3.1 Summary

The three project areas represent three levels of development ranging from the very poor area in Northern Mozambique with slash-and-burn farming, a very low literacy rate and no modern infrastructure or industry, to the more developed Gota Verde area in Honduras dominated by commercial farming, a market economy and small-scale industry. The conditions in the project area in Mali fall between those in Mozambique and Honduras.[4]

The projects achieved most of their original goals with regard to area planted with Jatropha and technical development and implementation, such as presses, biodiesel production and conversion of engines to run on pure Jatropha oil. In some cases, the goals were exceeded and research needs that were not foreseen were resolved.

3.2 MALI

Title: Garalo Bagani Yelen

Subtitle: Jatropha fuelled rural electrification for 10,000 people in the rural commune of Garalo, southern Mali.

The project name means "Garalo Jatropha Light" in the local Bambara language.

3.2.1 Goals

The project's aim was to reduce poverty and contribute to the "greening" of the area by setting up local Jatropha production and to provide 300 kW village electricity production capacity with Jatropha fuelled generator systems for 10,000 people in the rural commune of Garalo, Mali.

The project was to provide high quality modern energy services to the local population and to stimulate the local economy. Electricity itself was to be a catalyst for many small- and medium-sized business opportunities, and the sale of Jatropha seed was to generate new revenues. It is an enterprise-centred project, capitalising on Mali Folk Centre's (MFC) experience of rural

[4] ***Table 1: Comparison between the three countries***

	Mozambique	**Mali**	**Honduras**
Human Development Index Rank	184	175	121
GNI per capita (US$)	898	1123	3443
Intensity of deprivation : Average % of deprivation in education, health and living standards	64,6 %	64,4 %	48,9 %
Mechanization level	Very Low	Low	Medium High
Rainfall	800 mm	900 mm	1200 mm

Resources: Human Development Report 2011 UNDP energy enterprise development, combined with capacity building and participatory community development.

Expected main results of the project were:

1. 10,000 people benefit from clean electricity services supplied by a viable town electricity service company including 300 kVA generating capacity & 400 connections; electricity plan for next 5-year extension developed;
2. 1,000 ha village plantations of Jatropha and other oil-producing plants established, covering the village electricity needs for production of technical quality Jatropha oil (composing pressing, sedimentation and filtration equipment) and all levels of people trained to carry out the dedicated tasks and functions in the system;
3. Environmental benefits with CO_2 emission reductions of 9,000 tonnes/annum (135,000t over the project life of 15 years) and protection of soil against erosion to combat deforestation & desertification.

3.2.2 Target groups

The target groups included farmers, small entrepreneurs, and social service providers like schools and hospitals.

Figure 1 Oumar Sogoré, tailor in Garalo.

Garalo is located at a crossroad and hence has a lively high street with many small businesses including wood- and metalwork workshops, providing services to people in the village and those passing through. The population is engaged mainly in agriculture (mostly millet, sorghum and rice, as well as cotton for income generation), cattle raising and fishing.

There are approximately 100 enterprises, small businesses and shops in the village, as well as local government buildings, schools and clinics.

The population of the village is well organised, with dynamic local leadership. The population supported the project, as did the authorities (the local municipality mayor and his staff) and all parties expressed their commitment to the project, and their readiness and willingness to pay for electricity if available.

3.2.3 Project partners

The project partners were:

- MFC (Mali-Folkecenter Nyetaa, Mali's leading clean energy NGO),
- ACCESS S.A.R.L. (an innovative Malian rural energy service company),
- FACT Foundation (technical advisor),

- AMADER (Malian Agency for Development of Domestic Energy & Rural Electrification, set up as part of a World Bank/GEF/Government of Mali project to support rural energy development),
- Stichting Het Groene Woudt (for rural development components), and
- Stichting DOEN (funding).

3.2.4 Project context

Garalo is a town and rural commune situated in the Bougouni Circle in the Sikasso region, about 215 km from Bamako. The population that was estimated at 19,800 inhabitants in the 2001 census is essentially agricultural and consists of various ethnic groups such as: Sarakolés, Peul, Bobos and Bambara.

The main cash crops are cotton and groundnuts. Common food crops are maize, sorghum, millet, rice, fonio and vegetables. Fruit tree cultivation is considerable (mango, banana, citrus, etc.). The good quality pastures found in the area are grazed by cattle, sheep, goats and poultry. Transhumance is a source of conflict between farmers and herders in the area.

Garalo is located in the cotton zone. The producers are organised and supervised by CMDT among cotton producers' co-operatives in each village.

3.2.5 Project achievements

Figure 2 The power house and the start of the grid at Garalo Mali.

The project was set up by the Mali Folke Centre in June 2006, and planted 530 ha of Jatropha in different villages in the commune of Garalo, mobilising 430 producers.

The producers were organised into 35 village committees.

A co-operative named Bagani was formed to ensure the collection of seeds from the Committees and the processing of the oil seeds. The company ACCESS electrification Rural-based Bougouni planned to operate its generators on Jatropha oil.

The Garalo village electrification project in Mali formally ended in December 2009. FACT staff last visited Garalo in November 2009, and the power plant was being very well operated and maintained by local staff. Electricity demand steadily increased, and the electricity supply company (ACCESS) reached financial sustainability.

The Jatropha production caught on slower than anticipated and fuels other than Jatropha are therefore currently used for electricity production.

From 2010, the project is being replicated in 10 villages.

3.3 MOZAMBIQUE

Title: "Jatropha oil for local development in Mozambique"

Subtitle: Biofuel for Development and Communal Energy Self Supply

3.3.1 Goals

The objective of this pilot project was to develop a local market for pure plant oil (PPO) derived from Jatropha seeds produced by subsistent farmers in remote rural areas of Mozambique. The infrastructure, technical and human capacity was to be established to enable autonomous up-scaling of the activities after termination of the project.

The project targets were to grow 250 to 500 hectare-equivalents of Jatropha in hedges; to build up a viable oil processing facility; and to adapt 20 diesel engines already in use by small enterprises and schools for operation on PPO. The organisation and training of farmers and technicians is an important component of the project.

3.3.2 Project area & target group

The anticipated project location in Chimoio, Manica Province was changed to Bilibiza, in Cabo Delgado Province. This change came about because ADPP and GAIA had experiences of poor plant growth and pest attacks in Manica. ADPP in Bilibiza liked the project and knew of old Jatropha plants already growing well in the area.

The project area is located in the coastal zone of Cabo Delgado Province in an area with a population density below 18 people/km^2. The population is 76% Muslim and 72% belongs to the Macua tribe.

Figure 3 Farmers in front of their Jatropha hedge in the dry season.

The dominant soils are Cambisol and Acrisol with some Chernozem (INIA-DTA, 2002, FAO classification). Most of the project area is within agro-climatic zone R8 (INIA, 2000) with annual rainfall around 800mm (INIA-DIA, 1999). The bedrock is close to the surface and waterlogging is common in low-lying areas during the rainy season.

Shifting cultivation with permanent dry season settlements is the dominant land-use practise. During the cropping season, farmers move to shelters in the fields to avoid walking long distances and to protect the crops against wildlife.

The area is dominated by a subsistence economy that relies on food self-sufficiency. No external inputs are used. Cash crops have lower priority than food crops and are produced in small amounts to pay for soap, salt, clothes, etc. There are virtually no off-farm employment opportunities in the area. Sesame is currently the most important cash crop. The major food crop is cassava followed by maize, rice and millet. Only 22.6% of the households reported that they produce enough food. The rest are under-nourished and 2% reported having lost a family member from malnutrition during the last year.

Cultivation is strictly by hand and available labour is therefore the limiting factor that restricts cultivation. The labour peak is caused by weeding which according to farmers constitutes 35% of the total labour hours during the rainy season. Chasing wild animals takes 30% of the labour hours.

Due to shifting cultivation, deforestation is going on at a very high rate. This fact, combined with lack of measures in water conservation, such as dams in rivers, is making water scarcity a severe problem, which will worsen over the years. Depending on the season, between 16% and 42% of the population have access to water from protected wells.

The government considers the project area as unsuitable for drilling wells, because the groundwater is saline at most locations. This could mean that complete villages have to move to other places, making the pressure on water resources even higher. This problem could greatly reduce results of development efforts.

3.3.3 Project partners

Besides FACT, the partners involved were:

- ADPP, Mozambique,
- GAIA-Movement, Switzerland, and
- IIAM, Mozambique.

FACTs' strategy is to work with experienced partners, who have been working for a long time in the area with the target groups. To obtain knowledge of potential partners, a workshop was organised by FACT in Chimoio in 2006, to which stakeholders were invited. The experience with Jatropha was discussed and the participants were requested to draft proposals at the same workshop. The best partners were selected to join the final project proposal which was then written by FACT and the GAIA Movement, with inputs of Flemming Nielsen, who at that time was working for IIAM in Mozambique.

3.3.4 Project achievements

Four major project elements with specific targets were formulated:

1. To create between 250 and 500 ha of land cultivated with Jatropha;
2. To obtain knowledge of the most efficient variety;
3. To develop a local market for the oil; and
4. To establish a training centre on biofuels in Mozambique.

The major activities were staggered over three phases: The first phase focused on the introduction of Jatropha to the farmers' clubs established by ADPP, and simultaneously research on Jatropha began. The second phase focused on market aspects, technology development and research. The last phase (2009-2010) focused on developing a training centre, and organising courses to enable sharing of the generated knowledge, improve the regional knowledge base and provide revenues for the centre. The plan was to set up an oil-producing factory that would be able to operate on purely commercial terms.

Currently a "prototype" value chain is in place. All problems ranging from seed pre-treatment at one end to the effect of using JPO in diesel engines was researched and solutions were found for the problems that cropped up. The value chain works technically, but it remains fragile. At the end of the project, it looked as if it could be both profitable to the farmers and to the processing plant (BBC), but it will take at least a few years before firm conclusions on this can be reached.

Figure 4 Local maize mills like this one can be converted to run on Jatropha oil.

The specific purpose of the project of developing a local market for Jatropha was not achieved within this period, but the possibility to do so is still realistic. The oil-processing plant (BBC) is operational but the harvest of Jatropha seeds is low but continues to increase.

More and more variables assumed in the business plan have been confirmed by reality checks, indicating that it is possible to set up a profitable business with Jatropha for oil and other products like soap. The main partner, ADPP, has committed itself to continue operating the oil processing plant and has developed a new business plan and proposals for continuation.

More than 600,000 living Jatropha plants were established by 36 farmers' clubs (each including 50 farmers) in the area of about 75x100km, far exceeding the project target of 250,000 plants. These are mostly placed in hedges around farmers' fields of crops such as maize and cassava.

During the project, the Jatropha seeds were bought from farmers for MZN5/kg (USD0.18/kg). However, to make the business profitable from selling only oil from Jatropha as PPO (pure plant oil) as diesel replacement, the maximum price possible would need to be MZN2.5/kg (USD0.09/kg). If more valuable products like soap are produced and the press cake is also utilised, then a higher price can be paid.

The cost of fossil fuel is also an important consideration. Since Mozambique recently decided to stop subsidising fossil fuel, the value of JPO is expected to increase, which will lead to a higher payment to the Jatropha farmers.

The Jatropha project in Mozambique ended in December 2010. However, the main local partner, ADPP, is continuing the activities to develop a local market for pure plant oil (PPO), concentrating on diversification of products, of which soap is an important one.

Trial plots comparing different accessions of Jatropha have been established; but since all the plants are still years from reaching a high and stable yield, conclusions cannot be made at this time.

The training centre was established and courses in Jatropha production have been implemented on a commercial basis. The facility can provide full board and lodging for extended periods.

3.4 HONDURAS

Title: Promotion of small-scale biofuel production and use in rural Honduras

The acronym of the project, “Gota Verde” (“Green Drop”), is an indication of the approach: small-scale biofuel production for the local market.

3.4.1 Goals

The overall objective of the project is to demonstrate the technical and economic feasibility of small-scale biofuel production for the local market.

The specific objectives can be divided into three categories:

1. Agricultural: to improve know-how on and create visibility of the potential of biofuel crops;
2. Technical: to improve know-how and local experience in the field of appropriate biofuel processing and engine adaptation technologies; and
3. Enabling environment: to create a favourable socio-economic and financial environment for successful introduction of small-scale biofuel production and use.

These specific objectives have been further subdivided into seven Work Packages (WP):

1. Co-ordination;
2. Enterprise and market development;
3. Agricultural development (production and research);
4. Biofuel processing;
5. Diesel engine adaptation for PPO;
6. Dissemination in Central America; and
7. Dissemination in Europe.

3.4.2 Target groups

It was initially foreseen that the project would work mainly with medium-sized farmers, because small farmers were expected to show little interest and capacity to invest in a new, unknown cash crop (Jatropha). In practice, many small farmers did show a great deal of interest, especially if the crop was presented as an intercrop with other, edible crops. Although this shift to smaller producers implicated additional costs, the impact of the project increased and the experience has become richer: different types of farmers require different approaches.

3.4.3 Project partners

- STRO
- FUNDER
- FHIA
- Ageratec
- IEEP
- FACT
- Dajolka
- Hivos

3.4.4 Project context

Yoro Province, with its capital of Yoro, is one of the 16 provinces ("departments") of Honduras, located in the north of the country. The province consists of 11 municipalities, of which the project covers 8. Yoro province has an estimated 350,000 inhabitants, with a population growth of approximately 2.5% per year. Yoro is also the province with the third highest rate of emigration to the United States, a clear indicator of the lack of economic opportunities in the region. 43% of the province's population lives in rural areas. The main economic activities in the intervention area are wood exploitation (including much illegal activity), cattle rearing and the cultivation of basic grains (maize and beans). Remittances from family members working in the U.S. form an income source of growing importance.

Figure 5 Farmers with their Jatropha intercropped in maize.

The average rainfall in the city of Yoro is about 1,200mm per year, concentrated mainly in the months of May until November. The southern part of the department tends to be dryer and the rainy season shorter. Rainfall, temperature and altitude in most parts of Yoro province are considered adequate for the cultivation of Jatropha.

In October 2008, the north and east of Honduras was hit by Tropical Storm #16. It was by many farmers considered to be the worst natural disaster since Hurricane Mitch struck Honduras in 1998. Statistics indicate that more than 40,000 people were displaced and more than 72,000 ha of agricultural land (almost 10% of all land under cultivation in Honduras) were affected. The project lost 25 ha of oil crops (about 7% of the total area planted with Gota Verde support); these comprised 12 ha of Jatropha, 5 ha of castor bean and 8 ha of sesame. An analysis of the causes of the losses has led to more strict selection criteria for both the location of the plantations and the period of establishing the plantations (per crop).

3.4.5 Project achievements

The first phase of the Gota Verde project in Honduras (2007-2009) has been completed. In 2009, 114 ha of Jatropha were planted which brings the total to 360 ha. Some 125 ha of intercrops were also established in 2009 (pepper, maize, beans, sesame, sunflower, soy bean). Biofuel production in 2009 amounted to 3,675 litres of biodiesel and 1,260 litres of PPO, and a small experimental amount of cooking oil. The participant FUNDER created the “Gota Verde Centre” which aims to promote small-scale biofuel projects with a local focus in Central America. For follow-up, HIVOS has approved a second phase 2010-2012 and TechnoServe has approved funding for the expansion of 200ha of Jatropha with intercrops in 2010 (FACT annual rep 2009).

4 Context

4.1.1 Fossil fuel prices

The year 2008 was one of the most turbulent years of modern economic history. The worst financial and economic crisis since the 1930s affected the project's results in several ways. The world market oil price fell from an all-time high of USD147 per barrel in July 2008, to less than USD40 in December 2008.

As a result, production costs of PPO and biodiesel became higher than pump prices. Virtually all biodiesel producers in Honduras stopped producing. In 2009, oil prices started climbing again.

Figure 6 Crude oil (petroleum), price development 2005-2009, in USD per barrel.

4.2 National policy environment

4.2.1 Mali

In Mali, with the advocacy and lobbying work of the MFC, awareness was raised in the government on the opportunity of using Jatropha in rural electrification. Since the government had already given priority to rural electrification with diesel generators, it was now time to seize the opportunity for Jatropha and other oil plant species. The project fits well to existing policy documents such as the Strategic Document for Poverty Reduction and the National Renewable Energy Strategy from the project description for Garalo.

4.2.2 Mozambique

The Mozambican government has since the start of the FACT/ADPP project developed a comprehensive biofuel strategy because it sees biofuel as having a great potential in Mozambique. It wants to promote biofuel production to stimulate socio-economic development, especially in rural areas (PARPA) and to obtain a diversification of the energy mix to reduce dependency on fossil fuel imports.

To achieve this, Mozambique's National Biofuel Strategy prescribes the establishment of a national biofuel market with compulsory national blending targets for E10 and B5; the promotion of local processing capacity to add value; the increase of biofuel tax to support the buildup of the domestic sector (however with tax-exemption for vegetable oil for stationary engines).

The National Strategy also pays attention to sustainability and emphasises promotion of feedstock according to the recently finalised agro-ecological zoning exercise; avoiding the use of basic food crops and monocultures; enhancement of biodiversity; certification of biofuel production and socio-economic development. The selected feedstocks are sugarcane, sweet sorghum, Jatropha and coconut.

An assessment of Mozambique's biophysical potential carried out between October 2007 and May 2008 by an inter-ministerial working group found that of the identified 7 million ha, 3,780,933 ha (54%) was suitable for agriculture (including biofuel developments); the other 3,185,097 ha (46%) was suitable for other purposes, such as forestry and grazing (Government of Mozambique, 2008).

Biofuels are envisioned as a means of promoting development in remote areas. However, most of the present biofuel developments are in areas with good infrastructure: i.e, roads, facilities, health care and relaxation services, goods, (tele-)communications, (skilled) labour availability.

An analysis shows positive macroeconomic benefits and that approximately 150,000 new jobs will be created based on modest expansion to 450,000 ha (direct and indirect employment).

Only few projects are located in remote, rural areas. The FACT/ADPP project is one of them. Most of the projects are commercial projects focusing on premium markets in EU in absence of domestic and regional market, very few projects are aimed at local market development and involvement of rural smallholders.

4.2.3 Honduras

The Honduras government has adopted legislation aimed at making investments in the biofuel sector attractive by issuing several fiscal incentives. At the same time, however, fuel prices are a politically sensitive topic. Governments (and almost the entire population) tend to see fuel rather as a cost item than as an income and employment-generating opportunity. This translates into a policy of fuel tax cuts or even fuel price subsidies in times of high oil prices. Although this is perfectly logical from the electoral point of view, it can undermine long-term investment in the sector and thus the creation of income and employment opportunities for thousands of rural farmers and entrepreneurs, in spite of the favourable law.

On June 28 2009, Honduras' President Zelaya was sent into exile by the military. Many countries advised their citizens to avoid traveling to Honduras. Some of the activities involving European participants in the project, had to be cancelled for this reason. The operational work in Yoro did not suffer greatly, because the turmoil became more and more concentrated in the capital Tegucigalpa and the curfews were not applied strictly in the rural area of Yoro.

4.3 External factors of influence in Honduras

During the preparatory stage of the project, Crude Palm Oil (CPO) was identified as a viable alternative to start biodiesel production. CPO prices almost tripled in 2007-2008. In the second half of 2008, in response to the worldwide recession outbreak, prices fell back again. In 2009, prices started climbing again to historically very high levels.

Figure 7 Crude palm Oil (CPO) price development 2005-2009, in USD per MT

The consequence of this development for the project was that no feedstock was available to make possible commercial scale biodiesel production during the starting phase. Alternatively, waste vegetable oil was used as a feedstock.

5 Agronomy

5.1 Summary

Jatropha is easy to cultivate and manage. Even with close to zero management and no inputs applied, it was found that Jatropha produces seeds when the agro-climatic conditions at the site are right. Better management and application of manure increases the yield.

Much experience was gained with different propagation techniques, spacing, pest management, planting sites, pruning and other management practices. However, much uncertainty remains about what constitutes best practices for maximising yields.

In the three projects, Jatropha took longer to yield and yielded less during the project period than expected. By the end of the projects, the Jatropha plants were still immature and the yields still climbing. Elsewhere, Jatropha yields have taken eight years to reach their maximum level so it may still take years before this happens at the project sites. The level at which the yields will eventually stabilise at these sites is uncertain.

At this point, the yield variations between and within fields are significant and the reasons are not well understood.

5.2 Main lessons learned

- Jatropha grows in a wide range of agro-ecological conditions but is susceptible to compacted soils and to weed competition.
- Jatropha growth is limited under marginal conditions and responds well to the availability of nutrients and water.
- Jatropha is easy to propagate.
- No “weediness” has been observed. Jatropha grows where it is planted but does not spread on its own in the landscape; it is not invasive.
- Jatropha survives severe drought but is susceptible to waterlogging.
- Jatropha took longer to reach maximum yield than expected when the projects started. In the three projects, yields are still increasing and the maximum production appears not to have yet been reached. The only reliable data series that exists indicates that it takes about seven years before maximum yield is reached. The yield increase follows an S-curve with a slow increase the first few years followed by a rapid increase that levels off the last years before maturity is reached. Since none of the reliable long-term data comes from the project areas, they should be used cautiously when forecasting yields. These three projects (as well as most other Jatropha projects) only include plants that are three years old.
- Towards the end of the project cycle, the seed yield in Mozambique had reached a level that made it economically attractive to farmers. This was however not the case in Honduras, and it is uncertain whether the yields will ever be high enough to make Jatropha worthwhile there. In Mali, Jatropha appears to only be attractive to some farmers.
- The long time to maturity makes it important to create other incentives for the first years. In Honduras and Mali, intercropping food and cash crops in Jatropha plots was

used successfully. In Mozambique, Jatropha was part of a "package" that included wells and vegetable gardens which provided immediate benefits to the farmers.

- Pest problems are insignificant when grown under the right agro-climatic conditions. In Cabo Delgado in Mozambique, for example, pests and diseases are not of economic significance. Elsewhere in Mozambique with other agro-climatic conditions, however, pest problems have been severe.
- If comprehensive pest management is required, the production of Jatropha quickly becomes unprofitable. No pest control measures were required in Mozambique and Mali. In Honduras, some pest control measures were used to battle termites, mealy bug and other insects.
- In Mozambique, termites are responsible for most of the limited pest damage that does occur.
- The yield is highly variable even between plants in the same field. Even cloned planting material shows high yield variations for reasons that are not yet understood. Soil research undertaken in Mozambique showed that soil nutrients can only explain a small part of the variation.
- It is expected to take up to eight years before full yield is reached and consequently little can be learned from the first few years of data.
- The understanding of what constitutes good versus poor sites for Jatropha is not solid;
- At present, only trial plantings can provide sufficient knowledge about how Jatropha will perform at a particular site.
- In Mozambique, farmers prefer to plant Jatropha in hedges where they serve both as boundary markers and a cash crop. In Mali, the preference for hedges versus plots varied between farmers. Plots were generally preferred in Honduras and it was found that soil compaction by cattle was a problem in hedges. In Mozambique, farmers prefer wide spacing between the Jatropha plants in the hedges. This gives the maximum yield relative to the amount of planting material used. Sometimes pepper and herbs are intercropped, but in most cases local vegetation of no economic value is left to grow between the Jatropha plants. In Mali, denser spacing is preferred, resulting in hedges that can better keep animals out but that may also stress the plants due to severe competition for water and nutrients. In Honduras, Jatropha plots used wide spacing to facilitate the growing of short cycle intercrops for short-term income.
- The nursery practices used in the projects were unnecessarily resource-demanding. Many ways of reducing the resources for propagation were identified, including: nurseries without shade roofs, bare-rooted seedlings, direct seeding, and use of wildlings. Jatropha is very sturdy and copes well with rough treatment.
- Farmers in Mozambique and Mali appreciate cuttings for their ease of propagation and because they yield sooner than seedlings. However, cuttings do not develop a tap-root and are therefore more susceptible to extreme weather and unable to tap water and nutrients from deep soil layers. A mixture of cuttings and seedlings can ensure early seed production while also ensuring that some plants survive extreme weather conditions.

- In Mozambique and Honduras, farmers are reluctant to prune Jatropha because they have no experience with pruning and do not find it logical that plants can produce more if they are cut down. In Mali, pruning of Jatropha hedges is unproblematic.
- Pruning is considered to be an easy task that can be done at the time of year when there are few other farming activities. No firm conclusion about the best season for pruning has been reached except that in Mozambique problems have only been observed when pruning in wet weather. Pruning is therefore generally carried out during the dry season. In Honduras, farmers find it important to take the state of the moon into account to indicate the pruning moment. Pruning is done in the dry season, a few weeks before the rainy season.
- The main harvesting period for Jatropha coincides with the harvesting of food crops at all three locations. However, it was found that Jatropha seeds can be left on the plants for several weeks with minimal loss, and be harvested after the food crops. Surprisingly, farmers in Mozambique still prefer to mix harvesting of Jatropha and food crops. They explain that harvesting of Jatropha is a light task that is appreciated as a break from more demanding tasks.

5.3 Planting sites and configuration

In Mozambique, farmers had a strong preference for boundary plantings. Plots of Jatropha are almost exclusively found in the demonstration plots that are owned and managed collectively by the farmers' clubs.

In Mali, the preference for hedges versus plots varied between farmers. In Honduras, plots were preferred with intercropping.

In the Mozambique project area, farmers are increasingly changing from scattered plots separated in the forest to “block” farming where a village locates all its fields adjacent to one another. This reduces the perimeter that must be guarded around the clock against wild animals during the growing season, but it also makes it necessary to demarcate the fields. Farmers use hedges to mark field boundaries and prefer Jatropha because it is easy to propagate; it does not spread by itself so it proves that the boundary is intentional, and finally it provides an income opportunity in contrast to the indigenous species that were previously commonly used for boundary markers.

Figure 8 Jatropha hedge being planted in shallow soil in Mozambique. Notice the trench to catch surface run off.

Due to its dual purposes, Jatropha is even being planted by farmers who do not intend to use it as a cash crop.

5.4 Planting material

Seedlings produced under well-controlled conditions in nurseries were promoted in the three projects. Seeds from different countries were tested but no firm conclusions about what constitutes the best planting material could be reached within the project period because the Jatropha plants take more time to mature. Big variations between plants from the same accessions were observed. Research undertaken with the University of Wageningen at the site in Mozambique showed that soil nutrients cannot explain the variation.

Farmers generally appreciate cuttings for propagation, because it is easy and the plants produce seeds sooner than plants propagated from seeds. However, because cuttings do not develop a tap-root, this practice was discouraged by the project staff at least initially. In Mozambique, the tentative conclusion was reached that mixing of cuttings and seedlings may be the best way of ensuring that good seed production is achieved soon while having the certainty that some plants will survive even the most extreme weather conditions.

Another advantage of cuttings is that high-yielding plants can be cloned in this way. That cannot be ensured with seeds due to cross-pollination. However in practice, farmers have so far not been selective in their choice of planting material. Also, the unexplained variation in yields discussed above makes it questionable if superior genetic material can be selected based on appearance.

Large seeds are preferred for propagation but no practical method for sorting seeds according to size was identified under Mozambican conditions. Sorting through shaking in simple containers did not work. In Honduras, mechanical seed graders are available. Seeds for plot planting were provided by the project and mainly selected by size and weight by simple propeller separator and hand sieves. The remaining seeds were used for processing trials.

Good germination rates were easily achieved with seeds between 2 and 12 months old. Preferred storage conditions are dry, cool and dark places.

5.5 Spacing

In Mozambique, farmers prefer much wider spacing in the Jatropha hedges than recommended by the project. The average spacing is 1.6m whereas the project recommended 30cm or less. Dense hedges are common in West Africa where they are used to keep chickens and small livestock out of the fields. In the project area in Mozambique, farmers do not plant hedges for this purpose but solely to demarcate field boundaries. Also, the main pests are elephants, wild boars and monkeys, which are unlikely to be deterred by a dense Jatropha hedge. Due to the wide spacing, the Jatropha plants experience little competition and have a good per-plant yield compared to what would be expected from dense hedges. The amount of planting material relative to the yield is optimised in this way; this makes sense because the farming systems are labour-constrained. The yield per meter is probably lower, but since there is abundant space in Mozambique for planting Jatropha, this is so far not an issue. However, lower yield per meter reduces the amount of seeds that can be harvested per hour, so closer spacing may be more optimal in the long run.

Figure 9 Jatropha plot in Honduras.

At the beginning of the project in Honduras, Jatropha plots were laid out in pure plantations and a spacing of 3x2m was often used. Later, when the need for a short-term return on investment was clear, spaces like 1x4m 1x5m 1x6m were implemented depending on the farmer’s wishes for intercropping and the potential for future mechanical harvesting.

5.6 Propagation

Forestry nursery practices for producing Jatropha seedlings were promoted in all projects. Seedlings were produced in poly bags with carefully prepared and sifted mixtures of soil, sand and manure. Raised nursery beds or platforms with shade roofs were constructed. Under the extensive farming management in Mozambique and Mali, few resources are spent on the plants when they grow in the fields and therefore the propagation process represents a major part of the resources used for cultivating Jatropha. Any savings in this area can make Jatropha more attractive to the farmers. In Honduras, nursery costs represented a relatively small amount of total investment and the quality advantage of nursery seedlings is therefore worthwhile. Seed selection, poly bags, manure soil mixtures, humidity and pest control were implemented to ensure the quality of the planting material.

In Mozambique, it was found that direct seeding works well in some areas and not at all in others. The local fauna appear to be the major determinant. The first leaves that emerge contain hardly any poison, and rodents, goats or antelopes will happily eat them.

Farmers are increasingly using wildlings found under their existing Jatropha trees for resource efficient propagation.

Figure 10 Wildlings like this one is popular with farmers for easy propagation of Jatropha.

In Mozambique and Honduras, it was also observed that shade is not required in nurseries. Moreover, direct sunlight on the emerging plants creates hardness and resistance in the plant material. However, the frequency of watering must be increased when no shading is used. Many Farmers' Clubs constructed nurseries under big shade trees to avoid having to maintain shade roofs. In Mozambique, Elaion Africa lda experimented extensively with bare-rooted seedlings and found they performed well. Since poly bags are expensive and hard to find, this represents a significant advantage. Furthermore, it makes transport much easier. Particularly where seedlings have to be transported long distances by bicycle and foot, this is an attractive option.

5.7 Soil fertility

In Mozambique, farmers traditionally do not use any soil amendments or methods for maintaining soil fertility. The project trained farmers in compost production and application but this is used on high-value crops like vegetables and not Jatropha. In Mali, the use of small amounts of compost and manure is common, and in Honduras chemical fertiliser is commonly used. Applications of NPK 12-24-12 and additional urea are generally used there. Seed husks after de-husking are used as mulch and organic fertiliser. Also, organic waste of intercrops like maize and beans are used as mulch for the Jatropha plants.

Some competition with adjacent crops is expected over time but in none of the projects were any signs of reduced crop yield in adjacent crops observed.

5.8 Pruning

In Mozambique, farmers are reluctant to prune because they have little experience in it and find it counter-intuitive to cut a plant down in order to increase the yield. Consequently, many farmers did not prune their Jatropha. However, in many cases, insect damage to the terminal buds did result in the branching that is one reason for pruning. The problem of branches becoming too high to reach still remains. In some cases, farmers realised the need for pruning when they tried to harvest seeds from branches 4m above the ground. Unfortunately, in many cases, they then followed the pruning guidelines for new plants (i.e., to cut the Jatropha down to just half a meter) which severely reduces the yield for some years. Among people involved in Jatropha production in Mozambique, there is no agreement as to the best time for pruning. Some of the plantations prune at the end of the rainy season when wound-healing is faster. We had however observed severe die-back in a few cases where pruning was carried out under wet conditions, whereas no problems were observed when pruning took place during the dry season. Consequently, farmers in the Mozambique project were advised to prune during the dry season, which also happens to be the time when there is not much else to do on the farm.

In Honduras, there is a strong belief in the relationship between moon position and plant juice flows. Correct lunar positions were used to determine the exact pruning moment, and the end of the dry season.

Due to the slow growth of the first plots of the Honduran project, several plantations were not pruned in the first year – but were in the second. This has a huge negative impact on yield potential and demotivates farmers to keep on investing as they do not harvest in the second year.

Pruning is easy due to the light wood and farmers are not bothered by the labour requirement.

In Mozambique, farmers generally do not have pruning knifes and the ubiquitous machete is used instead. As a consequence, some splitting of branches occurs which is not ideal. However, no problems due to this issue have been observed so far. In Honduras, the splitting of branches from pruning also occurred regularly without any problems.

In particular in India, viruses are spreading fast in Jatropha. In Mozambique, there are so far no reports of viruses in Jatropha and no symptoms were observed in the project area. However, as a precautionary measure, farmers were instructed to clean their machetes when moving between fields or to other crops. In order of preference, the available methods include flaming (i.e. drawing the blade through a fire), cleaning the blade in sand or rinsing in water. It is however unlikely that more than a few farmers will follow these instructions.

5.9 Pests and Diseases

In Mozambique, the project is located where the pest pressure is minimal. This was confirmed by a national survey of insects in Jatropha that was undertaken with the Eduardo Mondlane University. It did not find any other locality with fewer pests than the project area.

A few golden flee beetles and rainbow shield bugs can sometimes be found, but the damage is insignificant. Termites are the most destructive pest. During the dry season, they will sometimes eat all the moist tissue the whole way around the stem, thus killing the plant that soon falls over. This appears to happen mostly to plants that are stressed; e.g. growing on soil saturated by water during the rainy season or on exhausted soils. In other cases, termites have made mounds around Jatropha plants without harming them at all.

Figure 11 Yellow flea beetles attacking Jatropha in Manica Province where the conditions for Jatropha are sub-optiomal.

Experiments were made with organic pest control in collaboration with the Mondlane University. Cypermethrin and aqueous extract of leaves of Margosa (*Azedirachta indica*), Tefrosia (*Tephrosia vogelii*); and tobacco (*Nicotiana tabacum*) were tested for efficacy in controlling leaf beetles (*Aphthona* spp.) and green caterpillar leaf miner (*Stomphastis thraustica*). Cypermthrin was efficient for controlling both pests whereas the botanical method only had effect on the leaf beetles.

If pest problems remain at the current level in Mozambique, it is unlikely that control measures will ever be needed.

In Honduras, severe problems with termites (*Atta spp.*) have been observed in young plant material in nurseries and young plantations, and chemical control was carried out successfully. Some plantations have been infected with mealy bug (*Phenacoccus spp*), and red dot bug (*Hemíptera spp*) especially in weak plants. No severe economic damage was observed. Doves tend to eat Jatropha seeds but do not cause severe damage.

In Mali, termites have been responsible for 5-10% loss of plants in some fields.

5.10 Harvesting

In the project area in Mozambique, Jatropha yields peak one or two times per year depending on the location. It is not yet understood what factors determine if a locality has one or two harvests.

Figure 12 Farmers in Mozambique deshelling Jatropha seeds by hand before drying them.

The main harvest occurs throughout the country at the end of the rainy season, i.e. around March. The second peak is in October just before the rains.

Where water is readily available

throughout the year, smaller amounts of seeds may be produced at any time.

In Honduras, a relation between rainfall and flower induction was observed in the majority of the plantations (not fully uniform). Since two dry periods can be distinguished, two harvest peaks are common during the year in August and November. De-husking can be easily carried out by a hand-driven concrete mill which has a capacity of about 100kg per hour while having it continuously fed. Harvesting in Honduras is also manual, but no recent harvesting data are available. Small yields at the beginning of the Jatropha yield curve do not motivate farmers to harvest since the minimum daily wage is about USD4.

The seeds are harvested by hand. Trials in Mozambique showed that farmers could harvest 1-3 kg of seeds manually per hour including de-shelling. Without de-shelling they can harvest 5 kg per hour. These figures are expected to increase as the yields increase and thus reduce the walking distances required to harvest a kilo of seeds.

In Mozambique, Jatropha seeds are ready for harvesting at the same time as the major food crops. However, it was observed that seed shedding is low even if the mature seeds are left on the plants for several weeks. This has the additional advantage that air drying of the de-shelled seeds can be omitted in many cases. Seeds harvested soon after they ripen are spread on the ground to dry before being stored.

Farmers were encouraged to leave the Jatropha seeds on the plants till after the food crops had been harvested. However, most farmers prefer to harvest Jatropha and food crops simultaneously. They explain that during a day of harvesting, they like to mix demanding and light tasks. Picking of Jatropha is considered a light task and therefore offers a nice break from physically demanding work.

Higher yield and bigger bunches can increase the amount of seeds harvested per hour. However, bigger seeds may have the biggest impact because they also reduce the labour for de-shelling.

6 CONVERSION/ PRODUCTS / APPLICATIONS

6.1 Summary

The three projects showed that conversion and application of Jatropha oil is possible in poor areas in developing countries by modifying off-the-shelf components or by producing specialised equipment locally.

The projects did not last long enough to assess the wear & tear, longevity and long-term performance of the equipment. Feasibility, maintenance requirements, etc. can therefore not be assessed with certainty.

Appropriate technology solutions were sought but still it was found that in the poorest area (i.e., Mozambique), quality control and low skill levels were major issues. This is unfortunate because the poorest areas are also where Jatropha production appears most profitable.

Figure 13 Bio-diesel installation, Gota Verde, Honduras.

Much work remains to be done on optimising all steps involved in conversion and application. Standardisation of for instance conversion kits for diesel engines is essential for bringing the costs and required skills level down but remains elusive as long as the Jatropha sector stays small.

6.2 Main lessons learned

- Developing the oil processing unit requires an industrial approach, which cannot be achieved overnight. Guaranteeing the PPO quality is already a challenge in itself. To develop a commercial oil production unit, with or without co-operation with the farmers (as legal shareholders), is a major challenge in countries with a low level of development like Mozambique (i.e., low level of technical education, high illiteracy rate, hardly any small commercial businesses). Only in Honduras was the ”Bysa” established as a commercial unit with farmers as shareholders, producing biodiesel from waste cooking oil, but no Jatropha oil.
- Jatropha oil of sufficient quality for direct use in engines is only obtainable if harvesting, seed handling and operation of the presses are carefully managed. For biodiesel production, oil quality is not a major issue.
- Low quality Jatropha oil can be processed efficiently by simple neutralisation with caustic soda. However, the process is not economical, so high-quality oil should instead be assured through the right management of the production chain.
- Sedimentation and filtering with cloth and candle filters provide sufficient treatment of the Jatropha oil when used directly in combustion engines. For other uses like production of soap or biodiesel, sedimentation is sufficient.
- Pre-treatment of Jatropha seeds before pressing is not required.
- If the level of acidity is within limits, there is a high probability that the oil quality is in order. Determination of acidity with titration is therefore a good method to obtain an indication of the oil quality. However, the oil quality can only be determined exactly

with an accredited test laboratory, by executing the required testing of the PPO on the standards as set in DIN V 51605.

- It was found that the colour and transparency of the oil indicates the acidity level and can therefore be used in day-to-day operations for optimising oil quality.
- None of the projects had achieved sufficient production of Jatropha within the project period to perform extensive testing of processing and application of Jatropha oil. Consequently, the longevity of converted engines, and the durability and maintenance costs of processing equipment could not sufficiently be assessed.
- Strainer types of presses are a better option than a small cylindrical hole press.
- Hand-operated presses are generally not feasible for Jatropha oil extraction even in low-income areas.
- Presses should only be operated by trained operators. Otherwise oil quality, equipment maintenance and longevity will suffer.
- Stationary diesel engines with indirect injection (ID) can be converted to run on pure plant oil (PPO) for a low price.
- Standardised conversion kits are not feasible at the three project sites because many different models of engines are in use. This is problematic because of the extra skills and costs required for customised conversions.

6.3 Recommendations for further research

- Monitoring processing equipment wear and tear and maintenance over a longer time period is recommended because this will have great influence on the profitability and viability of Jatropha for local development.
- The presses chosen in the projects are relatively small and not specially designed for Jatropha. It is evident that these presses are not yet optimal for pressing Jatropha and that further R&D is required to increase efficiency of pressing.
- It is recommended to find and try out improved strainer presses for small-scale applications, in combination with various forms of pre-treatment like fractionising of seeds (with hammer mill) or pre-cooking of seeds.

Figure 14 Technician standing in front of one of the Deutz generators, Garalo, Mali.

- For filtered oil that is slightly outside the quality norms, a simple degumming process should be developed.

- It would be good to investigate how consistently high oil quality can best be achieved. This involves both practices related to harvesting, transport, storage, processing and distribution.

6.4 Conversion

6.4.1 Pressing

In *Note on Jatropha pressing for FACT pilot projects* (Beerens and de Jongh, 2008), the parameters to choose pressing equipment were described. After studying various cases of operational experiences with presses and asking quotations of presses, the following recommendations for selection of presses were made for the case of the Mozambique project:

It was expected that 250 ha of Jatropha would yield 250-500 tonnes per year after 3 years. For continuous press operation this means a required production capacity of 0.7 to 1.4 tonnes per day (or 90/180 kg per hour assuming an 8-hour working day). From a practical point of view, it would be better to have multiple presses with a joint capacity in the order of 150-200 kg/h. The advantage of using more than one press is that parts can be exchanged and production can continue if one of the machines fails. Furthermore, smaller machines are easier to operate and maintain for local artisans. Smaller machines also allow for gradual expansion of the project size.


Figure 15 Oil pressing in Mali.

Availability of dealers and spare parts within the regions is important too. Based on all the above considerations the following presses were identified as good options: the Sayari expeller or the 6YL-80; the 6YL-95 and 6YL-125 (DoubleElephants). For both Mozambique and Mali a Sayari press was bought as well as Double elephant presses.

In the Gota Verde project a different strategy was chosen. The aim was to manufacture a press locally. J. Fokkink of Biofuels was prepared to transfer the technology based on the Taby T70 cylindrical hole press to Honduras. It was built with his assistance at a technical vocational school near the project site, and then tested. After the project ends, this school should be capable of manufacturing and maintaining this type of press.

6.4.1.1 Main conclusions

In all the three projects, mechanical presses were chosen, since hand presses like the most commonly available Bielenberg press and the imported Piteba press were no option for the projects, due to the planned size of production. Experiments carried out with the mentioned hand presses before and during the project showed that it was too difficult to get sufficient oil out (less than 1 l/hr) compared to the labour put into it.

The experiences in the projects with the mechanical presses were limited, due to low availability of seeds. It proved however to be well possible to press mechanically, even without pre-treatment of seeds like cooking or fracturing.

The presses chosen in the projects were strainer presses in Mali and Mozambique (Sayari + Double-elephant 6YL-110 for Mali (3 presses) and one 6YL-80 for Mozambique); and a cylindrical hole press (1 Täby T70) in Honduras. From both a technical and an economic point of view, the strainer types of presses are a better option than small cylindrical hole presses. For details, see Jatropha Handbook.

The output of these presses is typically 1 litre oil of 5kg of seeds (measured in Mozambique) with a throughput of ca 70kg seeds/hour (measured by Raghavan).

6.4.1.2 Operational experiences:

Figure 16 The BBC Jatropha Processing Plant in Bilibiza, Mozambique.

From operational experiences of a number of other users of Double elephant presses in Mozambique, it was found that these presses could be maintained and they performed well. The industrial quality standard of both the Sayari and the Double elephant is not high. The Vyahumu trust could not supply certificates of the material of the screws, and the finishing of the screws is only by grinding, and no polishing is done (de Jongh, visit to Vyahumu in 2008). The Double elephant screw has been well-polished, but no certificate of material is available and in the casting, quite some holes were discovered. From other users of Double elephant presses (Brendon Evans), it was found out that these presses could be well maintained. Bearings were of standard SKF size and available in Mozambique. The main spare part to be regularly changed (at least once a year) is the screw, which is built up of parts shrunk down to fit to a central shaft. The only dealer in Maputo tripled its price for the screw in a few years, but dealers in South Africa were found that could supply them for a lower price.

Presses should only be operated by trained operators. Otherwise oil quality, equipment maintenance and longevity will suffer. In Mozambique the low literacy rate and lack of people with basic technical training makes this an important issue. In Mali the situation was slightly better and in Honduras this was not an important issue.

The operator from Mozambique was being trained for two weeks at Diligent in Tanzania to operate the Sayari press. Niels AnsØ started up pressing with the local operators for the double elephant presses both in Mozambique and Mali, while Joost Fokkink trained the Honduras crew.

The conditions of the seed quality need to be as prescribed in the Jatropha Handbook; besides needing to be clean, seeds should have a moisture content of approximately 6%; if they are dryer, they clog up the press very soon.

In all cases, a reasonably good metalwork workshop with trained operators/maintainers should be available, at or near the project, to provide proper maintenance, or even to manufacture presses as is the case in Honduras.

6.4.2 Oil purification

Oil purity is of little concern when Jatropha oil is used for soap and lamp oil. However, for use in combustion engines, the oil needs further processing.

The most simple and appropriate method to purify the pressed oil is only by sedimentation and filtering. For small-scale projects like in MMH, drums (Mali & Honduras) or handmade steel tanks with compartments (Mozambique) can be used for sedimentation as a first step.

Figure 17 Filtering Jatropha oil, Bilibiza, Mozambique.

As the next step, the cleaned oil can be pressed through plate filters (cloth) (see Jatropha Handbook) for further cleaning. This was done in all three projects.

As a last refining treatment, the cleaned oil can be pressed through candle filters with minimal opening size of 1 Mu (done in Mali and Mozambique).

6.4.2.1 Operational experiences;

Due to limited amounts of pressed oil, limited experience was obtained in the three projects regarding oil purification. Moreover, the first oil samples tested showed too high levels of acidity and phosphorous (see next chapter). Especially the percentage of clean oil versus sediment is of importance for the overall economy, but only indicative data were obtained (1 litre of clean oil out of 5kg seeds).

Of the possible treatment methods (see Note on oil quality), only neutralisation was tried in Mozambique. From the neutralising experiments with the cotton oil by Evans, it was learned that the acidity could be neutralised by adding water with caustic soda and heat, resulting in clean cotton oil and soap residues. Samples of both untreated cotton oil and treated oil were also sent by us to ASG (Analytic-Service Gesellschaft mbH) and results compared. Apart from the lowering of the acidity, other variables, such as phosphorous contents and particles, decreased to acceptable values for PPO too. Therefore, testing of all relevant variables should be done regularly in accredited laboratories, while determination of acidity with titration can be carried out more frequently in the workshop.

The neutralisation process consisted of mixing water with caustic soda and heating the mixture with the oil to 60 degrees, for half an hour. Acidity dropped from 17 to 3 which is nearly acceptable. However, it created another 50% of sediment, which makes it un-economical.

The colour and transparency of the oil is a general indicator for acidity level and other parameters. They are improving when the colour of the oil gets lighter, and the transparency improves. See photos.

Fig 1 Jatropha oil, before treatment left, acidity 17, after treatment right, acidity 3

Fig 2 Cotton oil, before treatment left, acidity 20.4 after treatment right, acidity 0.08.

6.4.2.2 Recommendations

- It is better to use non-chemical treated plant oil, i.e. only pressing, sedimentation and filtering.
- If the acidity and phosphorous levels of the filtered oil are far too high, the oil should not be used for PPO, but for other purposes like biodiesel or soap-making.
- For filtered oil that is slightly outside the quality norms for phosphorous and partical contents, a simple degumming process should be developed and tried out.

6.4.3 Oil quality

The DIN 51605 standard for rapeseed biodiesel was used as the norm for oil quality, as recommended in the FACT Jatropha Handbook.

6.4.3.1 Operational experiences

The first PPO produced in Mozambique and in Honduras was tested by ASG in Germany and it was found that it had far too high acidity and phosphorous levels. The Acid value was more than five times the allowable value for both sites and the phosphorous content was more than 50% too high. For test results, see the Jatropha Handbook

Acidity at this high level will ruin any engine in a short time. It was decided to use the oil for other purposes, making soap in Mozambique, and making biodiesel in Honduras. Little oil was produced after these first batches and no further samples were sent to ASG.

Table: Oil quality measured in European lab (ASG) of first oil samples of Mozambique & Honduras

Parameter	Mozambique	Honduras	DIN 51605
Acid Value (mg KOH/g)	13,34	10,59	Max 2
Oxidation stability at 110 Degree C (h)	11,6	10,3	Min 6
Phosphorous contents (mg/kg)	19,4	17,6	Max 12
Source:	*End report*	*D20a-D21*	

The quality of oil depends also on the time of harvesting, storage and transport conditions. Little knowledge exists on these issues at this time and sometimes it is contradictory. For instance, tests in Honduras showed that yellow seeds give the best quality oil whereas tests done in Mali found the yellow seeds have the worst acidity levels (Test done by Niels AnsØ).

Oil quality also depends on the operation of the press, e.g. high temperature increases the phosphorous levels.

The storage conditions of the seeds influence the oil quality. It was found in Mozambique that seeds stored too humid would mould and result in highly acid oil.

Based on the experience we recommend that seeds should generally be picked when fully ripe (black shell) and if they are too humid they should be dried in the sun before storage in bags.

Storage of the oil should not to be done in galvanised tanks, which leads to creation of polymers, blocking fuel filters. Storage tanks should be hermetically sealed from air, to avoid oxidation of the oil.

6.4.3.2 Recommendations for quality control of oil

- The colour and transparency of the oil is used as a guide for optimising oil quality on a daily basis.
- Staff members should to be trained to do the titration for checking the JPO acidity.
- From time to time a JPO sample could be send to an accredited test laboratory (like ASG) for the full testing.
- It would even be better to build up a small laboratory and attract a chemical engineer who could be trained at an accredited test laboratory (for Mozambique at Diligent in Tanzania) to execute the required for testing of the PPO on the standards as set in DIN V 51605.
- Alternatively it could be explored if for instance a nearby hospital or other laboratory (like in Pemba hospital Mozambique) could undertake the tests for a fee.

6.5 Products and applications

The process chain for the various products and applications

Input	**Process**	**Product**	**Process**	**Application**
Crude oil				**Lamps**, stoves
Crude oil	**Mixing water+soda**	**Soap**		HH use
Crude oil	**purification**	**PPO**	Modification of diesel engines	**Diesel engines, cars**
Crude oil	**transesterification**	**Biodiesel+glycerine**		**Diesel engines, cars**
Press cake	composting	Fertiliser		Agriculture
Press cake	Diluting with water	Biopesticide		Agriculture
Press cake	pressing	Briquettes		Industrial boilers
Press cake	Pressing + heating	Charcoal		Stoves

Press cake	Anaerobic digestion	Biogas + fertiliser	Modification of diesel-gas engines	Diesel-gas engines for electricity, cooking, lamps + agriculture

Note: the items in bold are applicable to all three projects.

The main product of Jatropha is crude vegetable oil and the main by-product is the press cake, obtained after pressing of the seeds. When a next processing step is applied the following products can be derived: PPO, soap, biodiesel, glycerin, biopesticide, fertiliser, briquettes, charcoal and biogas.

The range of products produced in the three projects is restricted to crude oil, press cake, and derived products such as PPO, soap, biodiesel and glycerin. These products were applied as follows:

Crude oil for lamps and making soap, PPO for diesel engines and cars, biodiesel for diesel engines and cars, and glycerin to make soap. The other derived products were experimented with, but not applied on a larger scale, like making fertiliser and biopesticide from press cake.

Market surveys in Mozambique showed that there is a great need for cheaper lamp oil, soap and fertiliser. According to the business plan made for the Bilibiza Oil Factory (BBC), it should also be possible and recommendable to develop a market for soap and maybe for fertiliser; if low-cost lamps can be developed that work on PPO, there could also be a big market for lamp oil.

6.5.1 Stationary diesel engines, and car diesel engines modified for PPO

Both in Mozambique and Honduras, diesel engines and cars were modified to run on PPO. The diesel engines in Mozambique and Honduras are small (10-20 HP) and used for driving maize mills and water pumps. In the Mali project, large 6-cylinder license produced Deutz engines were imported from China, and converted with a 2-tank system. These engines of 100 kW are generating electricity and are quite expensive. Small engines (size 10 HP) are used in Mali to drive Multi-function energy Platforms (MFPs).[5]

One main component of the Mozambique project was to develop low-cost modification kits for the local diesel engines and to perform endurance tests with modified diesels. Based on the tests carried out in the Mozambique programme (one endurance test in the Netherlands, one in Chimoio and two in Bilibiza), it became clear that due to the variety of diesel engine types plus the local unavailability of good-quality material for conversion, it was not possible to develop a universal applicable modification kit.

[5] MFPs are agro-processing centres comprised of a small stationary compression ignition engine driving various milling, grinding or pumping attachments.

The latest type of diesel engine which prevailed in the region was a Lister type Chinese diesel engine (Make Feidong-2 cylinder). Two of these were modified and running on PPO (cooking oil) at BBC in an endurance testing programme.

The duration of testing had reached approximately 1,450 hours by the end of 2010, but the amount of PPO used is not exactly known. It is estimated that PPO was used for at least half of the time. The engines are performing without troubles up to now. Prior to that, two Lister type engines were modified and tested: one in the Netherlands (over 600 hours successfully on PPO) and one in Chimoio (a Nissan 4WD car was modified to run on PPO, with a tropicalised Elsbett 1-tank kit), which did not run very long.

In Honduras, one small diesel was modified with a simple 2-tank system as that used for the Feidongs in Mozambique; and three cars, including a Toyota Hilux, were converted with a standard Elsbett 1-tank system. All three cars are running without troubles.

For the Mali project, three diesel engines were modified. The three Deutz (100kW) engines for the electricity plant in Garalo were modified with a 2-tank system. These engines have not yet run for a long time on PPO, since no Jatropha oil is available (at least one of the gen-sets was running on PPO for the inauguration, but after that there have not been seeds available). They have not yet been tested on vegetable oil with high acidity contents, but long-term testing on PPO is expected to be completed in 2011.

Figure 18 The parts of the modification kit

M. Basinger carried out a thorough experimental study in Mali with plant oil fuelled MFPs (this is not a FACT project). His approach and findings are in line with those of Niels AnsØ in his Mission report, leading to the main lessons learned elaborated in the next section.

6.5.1.1 Main lessons learned

- The often-mentioned statement in general literature that stationary diesel engines can run on PPO straight away (so, without modification of the engines) proved not to be true.
- If modification measures consist of: a 2-tank system, lowering of the viscosity by a proper heat exchanger, supplying of an extra PPO filter, having fuel line diameters increased, advancing of the injector time and increasing of valve opening pressure, while also performing the required maintenance; then the engine will perform well for a long time.

- A general problem with many small stationary engines is that the engine temperature is not controlled by a thermostat, and therefore these engines operate at a very low temperature which increases fuel consumption and wear, which can be directly damaging for the engine using PPO.
- It is possible to modify diesel engines in a way that they can run on good quality PPO, but it requires an experienced engineer to determine which modifications are needed, due to the large variety of diesel engines in use.
- Of the low-cost engines imported from China or India, the Lister types of diesel engines with one and two cylinders in the range of 10-20 HP, are sturdier, lower-costing and more suitable to run on PPO after proper modification –than other low-cost engines.

Figure 19 Fueling the modified Nissan in Mozambiqque with cooking oil.

- Running on good quality PPO with a suitable and well-converted diesel engine, requires no extra maintenance. Ordinary maintenance like regular changing of lube oil and fuel filters might increase depending on the engine; but more complicated maintenance requiring a skilled mechanic, like cleaning of injector nozzles or changing of piston rings, should not increase as compared to operating on diesel.
- Importing of reasonable low-cost kits from Europe is possible, but the idea of developing a universally applicable modification kit that can be made locally is practically untenable.

6.5.1.2 Recommendations

- More research on developing and testing of low-cost modification kits is needed.
- For areas where a large number of similar diesel engine types are used, like the Lister type in Mozambique and Mali, the producers of these engines (in China and India) could be urged to deliver engines modified for PPO right from the factory.
- More capacity needs to be built in promising countries, such as those in the sub-Sahel, in engine modification for PPO and maintenance.

6.5.2 Crude oil for applications in lamps

Within the three projects, only the Binga lamp (see the Jatropha Handbook) could burn on crude vegetable oil from Jatropha for a long time. In Mozambique, experiments were carried out with a variety of lamps, but they only burn for a short while. Since the Binga lamp is no more than an open glass of oil with a floating wick, it is not very suitable for rural households. It can be concluded from the projects that an adequate lamp burning on crude vegetable oil is not available yet.

6.5.3 Stoves

None of the three projects investigated crude oil-burning stoves. In “Jatropha Assessment”, it is mentioned that the Kakute stove from Tatedo is not working and the Protos stove from Bosch Siemens is also not successful in Tanzania due to high investment costs and much maintenance. There are stoves being developed for whole Jatropha seeds (see: http://jetcitystoveworks.com/default.aspx).

Using Jatropha oil indoors for either lamps or stoves gives off smoke. An investigation by Wageningen UR Food & Biobased Research on smoke emissions from lamps indicated that the level of emissions are higher with a conventional wick, but lower with a new type of wick. It was not yet investigated whether there is any presence of toxic materials such as phorbol esters in the smoke. It is highly recommended to investigate this further.

6.5.4 Soap from crude oil or glycerin

In Mozambique, good bars of hard soap were made of the Jatropha oil, mixed with caustic soda and water. Further experimentation looked into different shapes, additives, etc. Compared with the soaps available at the local market, it seems that producing soap at BBC will be a profitable business. Liquid soap was made from the glycerin produced as a by-product of the biodiesel in the Honduran Gota Verde project.

Figure 20 Jatropha soap production. Small molds like the one shown here are used for experiments.

6.5.5 Biodiesel from Jatropha and waste cooking oil

Only in the Gota Verde project was biodiesel successfully produced. In the beginning, this was with Jatropha oil but it later changed to waste cooking oil. The lowest quality waste cooking oil with a high level of free fatty acids (FFA) was used for the biodiesel production; the best waste cooking oil with acceptable FFA levels was used directly in the modified cars and the stationary engine.

6.5.6 Biogas and electricity with gas engines

Another option is to use the Jatropha cake, together with manure of cattle or humans to produce biogas for electricity generation and/or cooking for institutes or households. Gas or diesel engines can be applied to produce electricity. Also gasoline car engines could be used.

6.5.7 Recommendations

- Develop an adequate low-cost lamp burning on crude vegetable oil. Since no lamp working well on crude vegetable oil exists yet, it is highly recommended to develop an adequate low-cost lamp, since the market for vegetable lamp oil is large. This market could be taken over however by solar lamps or LED lamps on batteries, which are spreading fast in Mozambique and elsewhere.

Figure 21 Demonstration biogas system established by the project in Mozambique.

- Apart from soap, it is recommended to develop and market other products based on Jatropha oil, such as shampoo, shower gel, hand wash, disinfectant and mosquito repellent.
- Increase the productive use of press cake. From an economic point of view it is clear that the press cake should be used to raise income as well. Therefore, the needs in the project region should be studied and the following suggestions could be considered:
    - Make fertiliser by composting the press cake, and sell it back to the farmers as a commercial biological product;
    - Make biopesticides from the oil or cake by diluting it with water, to be sprayed on plants;
    - Develop various small businesses using the Jatropha cake: e.g. for briquetting, both for supplying larger institutes like hotels and small industrial boilers. However, there is not much experience with briquetting of Jatropha yet (see the FACT Jatropha Handbook);
    - Use Jatropha cake for producing charcoal for cities, in areas around towns where trees have nearly been cleared. Diligent in Arusha, Tanzania has some experience with these technologies (see the FACT Jatropha Handbook, Chapter 5); and
    - Diversify to edible oil products. Instead of using the pressing and purifying equipment for Jatropha seeds, edible oil-bearing seeds and nuts like sunflower, sesame, canola or groundnuts could be pressed. This gives a diversification in products and services, in line with food and fuel production.[6]

[6] For the BBC oil-processing plant in Mozambique, expansion to processing other agricultural products being cultivated in the area (like sunflower, sesame and groundnuts) could be investigated and included; for example, press sunflower and sesame seeds (with the second press specially dedicated to this) and produce cooking oil for local use. Commercial production of peanut butter is already being tested and looks promising. It has not been investigated yet if BBC can compete with other producers in the existing large market for these products. There is no industry yet in the region to produce peanut butter. Trials with the oil press showed that it is very easy to make peanut

Both in Honduras and Mozambique, pressing tests were carried out successfully with sesame, sunflower and groundnuts.

butter, which is a valuable product to increase health of the population in Cabo Delgado. If marketing is successful, the set-up of a separate factory for peanut butter could even be considered.

7 Socio-Economics

7.1 Summary

Few socio-economic issues arose from the introduction of Jatropha in the farming systems. In the three areas, this plant was already known as a wild plant, as a live-fence plant or as a medicinal plant.

Jatropha did not compete with cash crops for land where it was planted in fences that would have been established with other species if Jatropha had not been available. Where Jatropha was planted in fields, it mainly replaced other cash crops.

The flexible and low labour demand of Jatropha did not constrain the farmers but made it possible to use off-season labour productively.

In Honduras, Jatropha was accepted as collateral for loans. In Mali and Mozambique, it can increase resilience by providing an income source when other crops fail due to dry spells.

Both men and women were engaged in Jatropha production. The low requirements of Jatropha make it easy for even the poorest farmers to cultivate.

Figure 22 Farmer in front of a two year old Jatropha plant.

7.2 Main lessons learned

- In Mozambique and Mali, Jatropha was planted in fences that would otherwise have been established with other less valuable species. Therefore, no competition for land with food crops occurred.
- In Honduras, farmers are market-oriented and the issue of competition for land is therefore less of an issue as Jatropha mainly substitutes other cash crops. However, the projects did not promote monocropping but intercropping of plots or hedges.
- In Honduras, farmers could use Jatropha as collateral. This option was not available in Mozambique and Mali due to a less-developed financial sector.
- The labour input required for weeding, pruning and harvesting of Jatropha was found to be small compared to other crops. However, the value of Jatropha is also lower than that of many other crops.
- The major labour input required occurs during the establishment of Jatropha, but seed yields only pick up after several years. Keeping farmers motivated till they see the benefit of their investment is crucial for the success of the project. In Honduras, farmers got short-term income from intercropping. In Mozambique, attractive horticulture and water pumps were introduced together with Jatropha.
- In Mali, intercropping was promoted and farmers growing Jatropha qualified for receiving electricity from the Garalo plant.
- In the project areas in Mozambique and Mali, crop failures occur every few years due to low or erratic rainfall. Jatropha can often produce seeds for sale when other crops

fail and it therefore has the potential to improve food security. The right conditions for measuring this effect did not occur during the implementation of the projects, and the significance is therefore hard to assess.

- In Mozambique and Mali, Jatropha hedges demarcate fields and thus help to enforce land ownership.
- In Mozambique, shifting cultivation is common and land reverts to community ownership during the fallow period. It is not known what will happen when Jatropha is growing in fallow fields.
- Two studies in Mozambique found no evidence of gender bias in the Jatropha production. However, as yields improve and thereby the economic significance of the crop increases, this may change.
- The requirements for entering Jatropha production are low as no special tools or inputs are required, timeliness is not essential and seeds are produced even when management is almost non-existing. However, yields improve with better management practices.
- The three projects used different types of ownership of the oil-processing facilities. It is however too early to draw conclusions about advantages/disadvantages of the different set-ups.

7.3 Socio-economic issues in Mali

Jatropha has been grown in Mali for a long time and farmers are familiar with planting it for fencing.

Some farmers planted Jatropha in hedges that would have been established with other species if Jatropha had not been available. Competition for land with food crops was therefore not an issue. In other cases, farmers established plots of Jatropha. There are no reports of it being at the expense of food crops.

Figure 23 Shop with Electricity hardware items in Garalo.

The existing food insecurity in the project area appears to be mainly connected with precarious living conditions of farmers. Many producers of Jatropha perceive it as a revenue source that can help them avoid selling of food stocks.

A major concern for producers concerns the existence and stability of the market for Jatropha seeds. The value chain is not well-established or secure. This will affect the willingness of actors at all levels (farmers, NGOs, policy-makers) in their decision to invest or not in Jatropha production.

In the Mali project, farmers are out-growers. They have no share in the oil-processing unit, which is run by a separate organisation, namely the Bagani Co-operative, set up by the MFC. A building for pressing and refining has been constructed. From the project closure (December 2009) until present, Jatropha oil has not been produced.

7.4 Socio-economic issues in Mozambique

Food insecurity has been relatively high with 60.2% of the population responding that they did not produce sufficient food for their families. Production of food went down drastically during the dry season with 32.2% saying they were close to starving during this period. Death from hunger occurs regularly in the area. The population consists almost entirely of small-scale to subsistence farmers.

The immediate causes of malnutrition are diseases, poor sanitation and unclean water. The inadequate dietary intake is an important indicator of the low subsistence nature of food production in the area.

Acceptability of Jatropha was not an issue because it was known by farmers in the area as a medicinal plant and was already used by some farmers for fencing homesteads and fields. Some farmers find that Jatropha hedges are better than other plant at keeping wild animals out of their fields. However, due to the wide spacing applied, this claim is questionable.

Jatropha planting has proved popular with farmers and the number of farmers' clubs participating and the area they have planted exceed expectations. At the end of the project in December 2010, an estimated 600,000 plants were growing. A study in collaboration with the University of Copenhagen found no gender bias or cultural obstacles to the adoption of the Jatropha system. The data are however based on few interviews and more comprehensive surveys are required to verify this.

Theft of plants and seeds is a problem in several areas and farmers therefore prefer to plant Jatropha close to the homestead where they can keep an eye on them.

Figure 24 Farmers Club at Nanjua, Mozambique.

Due to the non-mechanised shifting cultivation agriculture in the area, labour is the major limiting factor. Land is still abundant for the time being. The population density is however growing so fast that shifting cultivation will soon become insufficient for feeding the population.

Jatropha was introduced with other activities that provide benefits in the short term, including a horticultural programme and the establishment of locally produced rope pumps. This created confidence and motivated the farmers to go ahead with Jatropha. From the second year on, the project team started buying the first Jatropha seeds from the farmers, showing them that it brought real income.

Farmers are guaranteed a minimum price for seeds by the oil factory established under the project. They are however free to sell elsewhere if they want. This was intentional, to make it possible for other vendors to enter and thus make the whole value chain more robust through more redundancy. However, in the short term this tactic appears to have backfired:

In the last year of the project, many farmers opted to sell to buyers from Tanzania that offered prices about ten times higher than the local oil factory. This was only possible because the seeds were being used for establishing new plantations. Unfortunately, it caused many farmers to lose trust in the project as they came to see it as exploiting them instead of aiding them. The resentment led many farmers to abandon harvesting of Jatropha during the last year of the project. Other farmers harvested and stored the seeds in the expectation that the buyers from Tanzania would come back. However, it appears that they have stopped operating, probably because they had purchased enough seeds to start their plantations. Seeds then spoiled due to the long storage period and ended up not providing any income at all. This only deepened the resentment among some farmers.

The farmers are not owners of the oil-processing unit yet, because of political reasons (see End report). The BBC oil-processing unit is run by the ADPP (a NGO) that has intentions to make legalised farmers' clubs become the shareholder of the BBC in the future.

7.5 Socio-economic issues in Honduras

In Honduras (Gota Verde), Jatropha is only promoted for living fences and in intercropping plantations. The project does not support the dedication of farmers' entire land to Jatropha. This helps to minimise the substitution of food crops.

Two important inputs for food production are credit and mechanised equipment. Mechanised equipment requires fuel (mostly diesel) to operate. Especially in developing countries, fuel supplies to rural regions are often unreliable. In June 2008, at the beginning of the rainy season, the Yoro region suffered from severe diesel scarcity, caused by a combination of poor planning by fuel importers and speculating fuel distributors. As a result, many farmers had to postpone the preparation of their fields. The project, on the other hand, could continue its land preparation plans thanks to its access to biodiesel.

The project has also experienced that, in the context of Yoro, the limiting factor for increased food production was credit access. The Gota Verde project achieved that small farmers gained access to credit for food crops, because of their increased income from the intercropping scheme. This even resulted in an increase of the planted area as well as increased productivity.

Farmers are out-growers with a contract and can have shares in the BYSA oil-processing unit as well. BYSA is thus owned partially by FUNDER (a NGO) and the farmers.

8 ECONOMICS

8.1 Summary

As explained in earlier chapters, Jatropha takes longer to reach maturity and high-yield levels than originally thought. In the three projects, the yield level has only reached a fraction of what is expected in a few years. All production runs have therefore been small batches and the assessment of the economics of a full-scale biofuel production chain consequently remains tentative at this stage.

The data from the three projects indicate that the Jatropha PPO value chain is viable in Mozambique but not in Honduras. In Mali, the Jatropha PPO may be marginally viable. In Honduras, Jatropha biodiesel production fares worse than Jatropha PPO. At the two other projects, only Jatropha PPO was produced.

Due to the slow maturation of Jatropha, significant costs are faced up front while an income is only building up slowly. It is similar to fruit production or forestry. Economic analysis should ideally cover the lifetime of the Jatropha system, but currently the experience is too limited to allow reliable long-term analysis.

Seed prices are currently high because significant amounts are used for establishing new plantations. This is a temporary situation and from the medium term, biofuel prices will be determined by the price of fossil fuel.

Jatropha is a low-value crop that can be produced cheaply. The experience from the three projects indicates that Jatropha is most profitable in marginal areas where farming techniques are simple, few inputs are used and where yields of alternative crops are low. In areas with poor infrastructure and poor world market access, fossil fuel prices are high and Jatropha is more competitive.

Improving the value of the by-products is a priority as that will significantly increase the profitability of the value chain. Work in this area has just started.

8.2 Main lessons learned

- In isolated areas, Jatropha PPO for local use benefits from high prices of the fossil fuel that is being substituted and the low farm-gate prices of other crops.
- Processing in isolated areas is more expensive and it can be difficult to get sufficiently skilled people.
- The production costs and energy loss from direct use of Jatropha oil in combustion engines are lower than with Jatropha-based biodiesel.
- Jatropha production by many dispersed small-scale farmers increases the transport costs. However, it was found that –even in Mozambique which had the project with the highest transport requirements– less than 5% of the fuel produced is used for transport.
- Consumers in the project areas are willing to pay a higher price for biodiesel than for PPO because it is considered less risky.
- At the beginning of the projects, high fossil fuel prices and low prices of vegetable oils made Jatropha oil and biodiesel highly profitable. As the fossil fuel price dropped and the price of plant vegetable oils increased, biofuels became less profitable.

- In Honduras, the production costs of Jatropha oil and biodiesel exceeded the cost of fossil diesel during most of the project period. PPO and biodiesel made from waste vegetable oil was still profitable.
- In Mozambique, Jatropha PPO appears to be profitable. A business plan that is based on the experience of the project in terms of production and costs indicates that Jatropha PPO can compete with fossil fuel while being profitable for farmers and the processing facility.
- Government subsidies of fossil fuels undermine the competitiveness of biofuels. In Mozambique and Honduras, the governments decreased fuel subsidies towards the end of the projects.

8.3 Yield

Yield is a main parameter in determining the profitability of Jatropha. However, it is important to understand that yield per ha is most important where land is in short supply, as it is in Honduras. In Mali and even more in Mozambique, there is more land available than farmers can cultivate. They are limited by the available labour, and the yield per working hour is therefore the main parameter in this situation. Furthermore, labour shortage varies with the season. In subsistence farming as it is practised in Mozambique and to some extent in Mali, there are times of the year where little labour is required. It was found that most tasks in Jatropha cultivation can be undertaken at times when there is no labour shortage. It opens the possibility for increasing the income in labour-constrained farming systems.

It was explained earlier that Jatropha takes longer to mature than expected at the time the projects were conceived. Its cultivation therefore has more similarities with fruit trees than with annual crops. The economic analysis should ideally cover the lifespan of the plants. However, Jatropha has an expected productive life of 20 to 30 years while data from only the first few years are available.

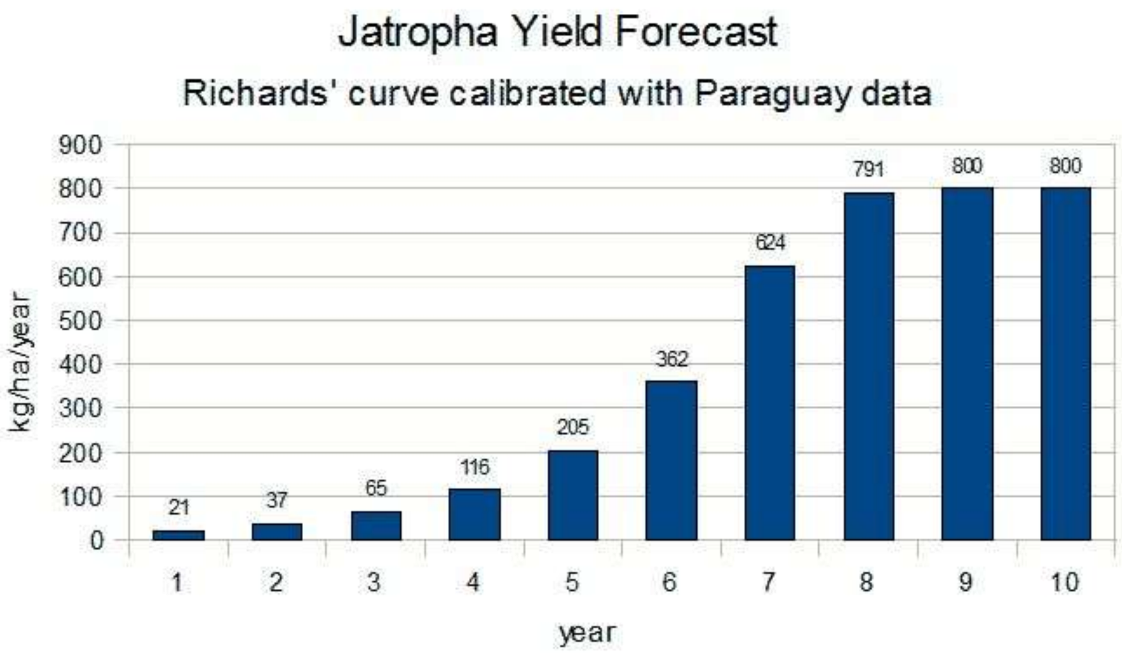

Figure 3 Yield forecast for Cabo Delgado, Mozambique

In Figure 3, the yield forecast for Mozambique is shown. The long-term trend is based on literature reviews, but the data for the first years are in line with what was observed on the ground. Some fields had significantly higher yields while others yielded hardly anything even after four years.

In Mali, yields of around 500 kg/ha after 2-3 years are reported for low-input agriculture. These figures appear to be from fields with good production and the average production is not known.

Figure 25 Growth of Jatropha in 17 months in Mozambique.

In Honduras, the best fields yielded 450 kg/ha after two years. Yield data from eleven farmers show an average of 79 kg/ha for one-year old plants, 248 kg/ha for two-year old plants and 214 kg/ha for three year-old plants. The spread between the farms is large; e.g. the data for two-year old plants are from two farms that harvested 398 and 98 kg/ha respectively. The project area was hit by Tropical storm #16 in October 2008, resulting in significant losses of Jatropha and other oil seeds.

8.4 External inputs used for Jatropha production

Jatropha is a low-value crop so the use of inputs quickly reduces the profitability.

In Mozambique, no external inputs were used for the Jatropha production and only labour for pruning, weeding and harvesting was required.

In Mali, the cultivation was slightly more intensive with some farmers using fertiliser.

The most intensive cultivation took place in Honduras where more fertiliser and labour were used.

8.5 Sales price

Currently there is a lucrative market for Jatropha seeds for establishing plantations. This is however ephemeral and therefore not considered in the economic assessments. There will of course continue to be a market for planting material but it is likely to be dominated by companies specialising in improved high-quality seeds.

The three projects focused on supplying the local market with Jatropha PPO or biodiesel. Because of the novelty of the fuel and the risks it entails, the price is likely to be lower than that of fossil fuel for at least some years. As the confidence in the new fuel grows, the price gap is likely to disappear.

On the international market, a high demand driven by fuel blending requirements in the EU and elsewhere can drive the price of Jatropha oil above that of fossil fuel. Again, since the three projects focused on local substitution, the international market price is not considered.

Poor infrastructure and long transport distances can increase the local fuel price. In the Mozambique project area, diesel is sold in jerry cans along the main roads at a markup of typically 20% compared to the pump price in larger towns.

Table 1 The effect of poor market access on diesel prices, Mozambique

Year	Diesel USD/l pump price (Pemba)	Diesel USD/l local price (Bilibiza)
2007	0.81	0.97
2008	1.29	1.55
2009	1.08	1.30
2010	1.48	1.78

The remoteness of the project in Mozambique makes local fossil fuel substitution more profitable by allowing higher prices to be charged for the PPO. Furthermore, it results in farmers receiving low farm-gate prices for their produce because of the high transport costs. In effect, it lowers the opportunity costs of Jatropha cultivation.

However, there are also disadvantages for Jatropha production in remote areas. Processing equipment is more expensive, it is more costly and time-consuming to get spare parts, and the lack of skilled labour increases maintenance costs, down time and product quality issues.

8.5.1 Economics of Jatropha cultivation

The sales price covers Jatropha production, transport and processing, each of which must be profitable.

In Mozambique, it was found at the end of 2009 that the minimum farm-gate price that farmers would accept was MZN2/kg (USD0.08/kg). A price of MZN2.5/kg (USD0.09/kg) is considered sustainable as it will be profitable for both farmers and the processing plant.

Tests showed that farmers can harvest 1-3 kg/h including de-shelling, or more than 5 kg/h excluding de-shelling. The value of one person’s work ranges from MZN22 to 240 (USD0.9 to 10) per eight-hour working day which compares favourably with salaries paid for manual labour. There is hardly any paid labour available in the area. During the implementation of the project, farmers who participated directly in the project were paid double the price to stimulate production. Farmers outside the project could sell to the project at the lower price. A significant number of farmers outside the project planted Jatropha on their own initiative despite being paid only the standard price and not the premium price offered to farmers within the project.

In 2010, many farmers opted to sell to buyers from Tanzania that offered prices about ten times higher than the project’s oil factory. This was only possible because the seeds were being used for establishing new plantations and Jatropha seeds were in short supply. Unfortunately, this situation caused many farmers to lose trust in the project as they came to see it as exploiting them instead of aiding them. The resentment led many farmers to abandon harvesting of Jatropha during the last year of the project. However, plants were not uprooted so production can resume when tempers have settled. Other farmers harvested and stored the seeds in the expectation that the buyers from Tanzania would come back. However, it appears that they have stopped operating, probably because they have purchased enough seeds to start their plantations. Meanwhile, seeds got spoiled from the long storage and did not provide any income at all. This only deepened the resentment among some farmers.

In Honduras, farmers were paid about USD0.10/kg. This appears to be sufficient to ensure some production but not high enough to drive a large expansion of Jatropha. As will be discussed later, the price is too high to make the Jatropha PPO and biodiesel competitive at the current fossil fuel prices. A lower price will make Jatropha unprofitable with the current yields but may be viable when the plants have matured and yield more.

In Mali, farmers were paid USD0.05/kg. Jatropha yielding 500 kg/ha were estimated to require 25 working days per year. In other words, Jatropha provided income of USD1/day which falls slightly below the legal minimum wage. As in Honduras, the price appears to be just enough to ensure some Jatropha production but not any significant expansion.

The press cake is a good fertiliser and returning it to the farmers where it will substitute chemical fertiliser can make the Jatropha cultivation more profitable. However, it reduces the options for getting added value from the press cake in the processing plant. One option that benefits both the processing plant and the farmers is to produce biogas from the press cake and return the slurry to the farms. This is currently being implemented at the three sites.

8.6 Transport

Small quantities of Jatropha produced by dispersed farmers increase the transport costs. However, in Mozambique where transport distances were longer and infrastructure worse than at the other locations it was still possible to keep the transport costs low.

Figure 26 Jatropha being collected.

With the 4t truck owned by the project, the collection of 100 kg of Jatropha seeds would require 0.95 litres of fuel on average in year three, dropping to 0.68 l per 100 kg as the yields increased. About 20-25 litres of PPO is produced from 100 kg seeds, so 4-5% of the fuel is consumed by transporting the seeds.

In Mali and in particular Honduras, infrastructure is better and production per farm is higher, so their transport costs are likely to be lower than in Mozambique.

8.6.1 Economics of Jatropha processing

At the initiation of the projects, the price differential between fossil and vegetable oils made biofuel production highly profitable. However, during 2008, the prices changed significantly and made any biofuel production uneconomical for a while.

In Honduras, BYSA's PPO and biodiesel production based on waste vegetable oil became profitable again from the end of 2009. Jatropha PPO and biodiesel production are still not economical.

Table 2 Cost and margin per biofuel in Honduras, end of 2009.

Product	Cost Price	Diesel Price	Margin (EUR)	Margin (%)
PPO from WVO	0.27 €	0.56 €	0.29 €	104%
Biodiesel from WVO	0.47 €	0.56 €	0.09 €	18%
PPO from Jatropha	0.77 €	0.56 €	-0.21 €	-27%
Biodiesel from Jatropha	1.13 €	0.56 €	-0.57 €	-50%

Source: Calculations provided by BYSA

The margin calculations assume no income from by-products, which is a worst case scenario.

If no value is gained from the press cake Jatropha biodiesel is only profitable if fossil fuel prices soar to around 200USD per barrel.

In Mozambique :

Table 2 Cost and margin for JPO in Mozambique end 2010

Product	Cost Price	Diesel price in town	Diesel price Bilibiza	Margin (EUR)	Margin (%)
PPO from Jatropha	0,83 € [7]	0,74 €	0,96 €	0.13 €	16%

The margin calculations assume no income from by-products, which is a worst case scenario.

8.7 Value adding of by-products

There is ample scope for improving the profitability of Jatropha PPO and biodiesel production by adding value to the by-products.

In Honduras, the main measures taken in order to reduce the vulnerability of BYSA to the world market price of oil are:

1. To deepen the production chain by generating as much added value as possible to the by-products of the biofuel production chain. Activities studied include biogas (e.g. for grain drying), organic fertiliser (effluent of biogas production), electricity generation and soap. BYSA already sold Jatropha seeds for reproduction and liquid soap (made from glycerin, a biodiesel by-product) in 2009; and
2. To diversify the income sources of BYSA by developing an edible oils production line. Edible oils follow a less extreme price development than fossil oil; e.g. during the period July-December 2008, when fossil oil prices fell more than 70%, soy bean and canola oil prices fell by about 50%. BYSA started to sell experimental quantities of cooking oil in 2009. The seed cake of the edible oil is also an excellent input for animal feed, a line studied by BYSA in 2009, giving additional income stability to the company.

[7] Including 17% VAT (exchange rate €1 =USD1.3)

The scheme below gives an impression of possible future extensions of the Jatropha biofuel production chain and its integration with other production chains, in order to increase added value throughout the production chain. Preparations have advanced to add a biogas and cattle fodder component in 2010. A biogas-fed grain drying installation may follow in 2011.

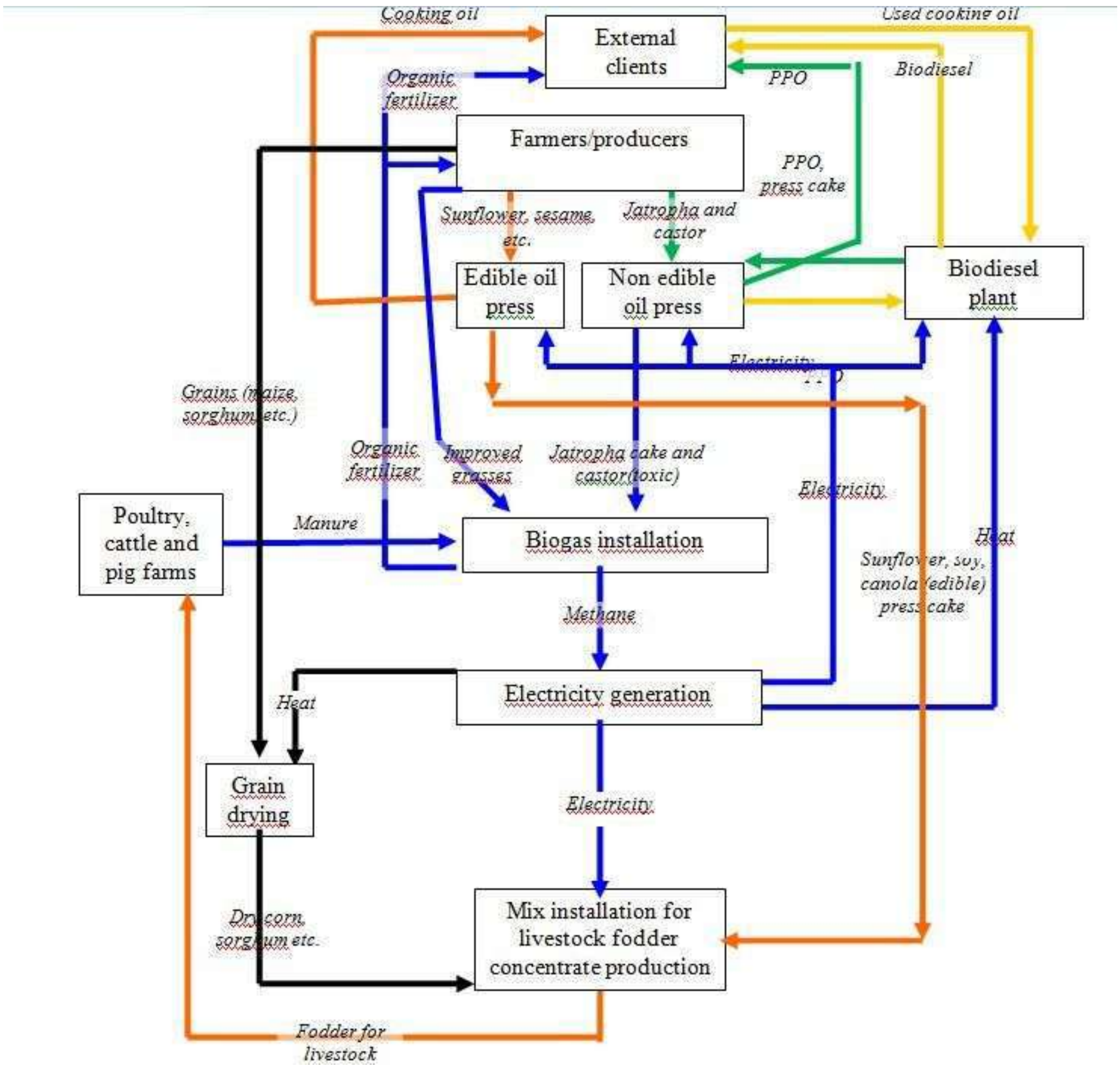

Figure 3 This graph provides an overview of the different possibilities to extend the Jatropha biofuel chain. The easiest way to read the figure is to start with the basic Jatropha biofuel chain (in green), followed by an expansion of a biodiesel processor (in yellow), an expansion of edible oil crops and cattle fodder (in orange), the expansion of a biogas installation (in blue), and finally the addition of a grain drying installation (in black). Obviously, the expansion process can follow a different order and can include fewer of the expansions mentioned here.

Crude palm oil (CPO) was identified as an alternative feed stock for biofuel production. Honduras is the largest exporter of palm oil in Central America. However, the prices almost tripled in 2007-2008, forcing the project to scale down the anticipated production levels and to abandon the purchase of professional biodiesel equipment. Instead, simple equipment was built locally.

In Mozambique, surveys showed a big market for lamp oil. It is sold in small quantities at a higher price than gasoline or diesel. Jatropha PPO that does not meet the quality requirements for use in engines can be used as lamp oil. However, as explained elsewhere in this report, no suitable design for Jatropha lamps exists yet.

Even if a suitable Jatropha lamp is developed it may be overtaken by the spread of cheap LED lamps. In Mozambique, this is already happening at a rapid pace. An analysis showed that Jatropha oil is not competitive with LED lamps under most circumstances.

In Mozambique, a biogas digester has been funded by other donors and will soon be installed at the oil-processing plant where it will run on agricultural waste and Jatropha press cake. The gas will be utilised in the Teachers' Training College and the Agricultural School situated next to the processing plant.

Until Jatropha reaches full production, the excess pressing capacity is used for manufacturing peanut butter and cooking oil.

PPO that does not meet the quality requirements for engine fuel is used for soap production which is currently more profitable than biofuel. Other oil-based products that are planned include laundry detergent, luxury soap, shampoo, shower gel, disinfectant and mosquito repellent. The target for a number of these products is the urban market in Pemba.

Figure 27 Jatropha seeds spread on the ground for drying.

9 ENVIRONMENT

9.1 Summary

The environmental impact of Jatropha production was minimal in the three projects. The area under cultivation hardly expanded. Instead, Jatropha substituted low-value tree species in hedges or other cash crops in the fields. No weediness was observed; i.e., Jatropha did not spread beyond where it was planted.

9.2 Main lessons learned

- Scientific studies undertaken in Mozambique indicate that the GHG and energy balance is positive if existing fields or fallow land are used for Jatropha production.
- If primary forest is cleared for Jatropha production, the carbon debt will only be paid back after 1,900 years of Jatropha production.
- No issue with weediness, i.e. uncontrolled self-propagation, was observed in the project areas.
- Minimal land-use changes have been observed. In Mali and Mozambique, Jatropha is substituting other species in hedges that would exist even if Jatropha had not been introduced. In Honduras, this is the case to some extent, but intercropping of annual crops is practised too. In this case, Jatropha mostly substitutes other cash crops that would otherwise have been cultivated in the same fields. In some cases, a slight increase in the cultivated area was observed.
- Due to the absence of weediness and minimal land-use changes, no impact on biodiversity is expected.

9.3 Biodiversity

It was feared that Jatropha would outcompete indigenous species and spread in the landscape. In some countries, including South Africa, it is therefore banned. However, Jatropha was introduced throughout the tropics more than a century ago and we are not aware of any examples of rapid uncontrolled self-propagation. Neither was this observed in the three projects.

The project in Mozambique is located inside a recently established national park, namely Quirimbas National Park and the biodiversity impact of Jatropha production is therefore an important issue. However, none of the stakeholders, including the Park Authorities, WWF and the several ministries involved have found it problematic; this is partly due to Jatropha having grown in the area for a long time as a medicinal plant, without spreading beyond where farmers planted it.

9.4 Carbon and energy balance

In Mozambique, a study of the carbon and energy balance of Jatropha production was undertaken in collaboration with the University of Copenhagen. It was found that the carbon balance depends on where farmers plant Jatropha. If they clear forest to plant Jatropha, it will take 1,900 years to pay back the carbon debt. If they plant in fallow fields, the carbon balance is good. No clearing of forest for Jatropha production has been observed.

10 CONCLUSIONS

The three projects have shown that different Jatropha value chains can work in poor areas in developing countries. However, they also show that the profitability is lower than expected and that only under some circumstances is Jatropha an attractive option. The three projects show that currently the main niche for Jatropha is in agriculturally marginal areas with abundant land and low-input farming systems.

When the three projects started, little was known about Jatropha production and processing. Assumptions and expectations were based on the best knowledge available at the time and indicated that highly profitable Jatropha value chains could be established under a wide variety of agro-ecological and socio-economic conditions.

The main factor that has affected these and other Jatropha projects is that the expectations to the capabilities of the Jatropha plant itself have turned out to be highly exaggerated. The yield is lower and it takes longer to reach than assumed. However, the sturdiness of the plant and its ability to survive under extreme conditions have largely been confirmed.

The indication is that after three or four years, the full yield has not yet been reached. Nobody knows for sure when the yield will level out and at what level, so an assessment of the viability of the Jatropha value chain is still not possible without making assumptions based on very limited data. The expectation is that the yields will continue to climb and stay at a high stable level for decades. Jatropha production that is viable after three to four years is therefore likely to become even more so as time passes.

On the processing side, assumptions have had to be adjusted too. Where Jatropha oil is used directly in engines it has turned out to be more difficult and more costly than anticipated, to reach sufficient quality levels.

In agriculturally poor areas where no fertiliser or pesticides are applied and soil preparation is minimal, it produces a fair yield as compared to other crops cultivated by the farmers. It even survives and usually yields even in years where drought wipes out other crops.

Such areas are often isolated, leading to high prices on fossil fuel. The project in Mozambique is the best example of this. The relative advantages of Jatropha together with the high fossil fuel price make Jatropha biofuel competitive. However, as the project experienced too, the isolation and low level of development also add costs. Processing facilities are more expensive and time-consuming to establish; the skill level of the operators is low and they tend to leave after a short time.

Honduras is the opposite of Mozambique, with more developed farming systems and economic integration. Fertiliser, pesticides and machinery are used and under these conditions other crops give a better return than Jatropha.

Mali is closer to Mozambique in terms of development indicators, but the project area has a much higher level of economic integration and activity. There are more alternatives for making a living including a wider selection of cash crops and off-farm employment. The area is less isolated so the fossil fuel prices are slightly lower than in Mozambique. All in all, Jatropha is marginally viable.

Each “link” in the Jatropha value chain is new and had to be established by the projects. They are prototypes that work but with much room for improvement.

When many prototype "links" are put together, the inefficiencies have a multiplicational effect and the overall efficiency of the value chain becomes low. If there had been biofuel value chains in the project area, the projects could have focused on introducing Jatropha as a new feedstock. Due to the incomplete knowledge about best practises for Jatropha production, they could perhaps have achieved 75% of the yield that a more mature system with extensive experience and skills can achieve. To be attractive to farmers, Jatropha needs to be competitive with other crops at this 25% disadvantage.

In these projects the production, processing and consumption (engine conversion) are prototypes. If the same 75% efficiency is achieved in the three "links" the efficiency of the full chain is just 42% compared to a more mature system. This is a much more severe disadvantage to overcome. It highlights the very experimental nature of these three projects and also why Jatropha value chains that are today only marginally viable are likely to become much more profitable as more experience is gained.

As shown throughout this report, more research is needed in every aspect of the Jatropha production chain. Some research will have to be done in labs and on research stations but adaptive research and development projects like the ones covered here play an important role in testing things under real conditions, getting feedback and ensuring that the right research questions are prioritised.

It is therefore important to continue adaptive research and development projects at localities where Jatropha has a comparative advantage. Currently, this is in agriculturally marginal areas with low-input farming systems, abundant land and high fossil fuel prices due to poor infrastructure. Millions of farmers live in such areas and currently there are few development options for them. Jatropha has the potential to play an important role in alleviating poverty for this target group.

With time, improved planting material will become available, better agronomic practices developed, oil processing and by-product utilisation optimised and engine modification kits or dual fuel engines will become cheap and reliable. That will likely expand the niche where Jatropha has a comparative advantage. However, until this happens adaptive R&D should focus on the areas where it is currently competitive.

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