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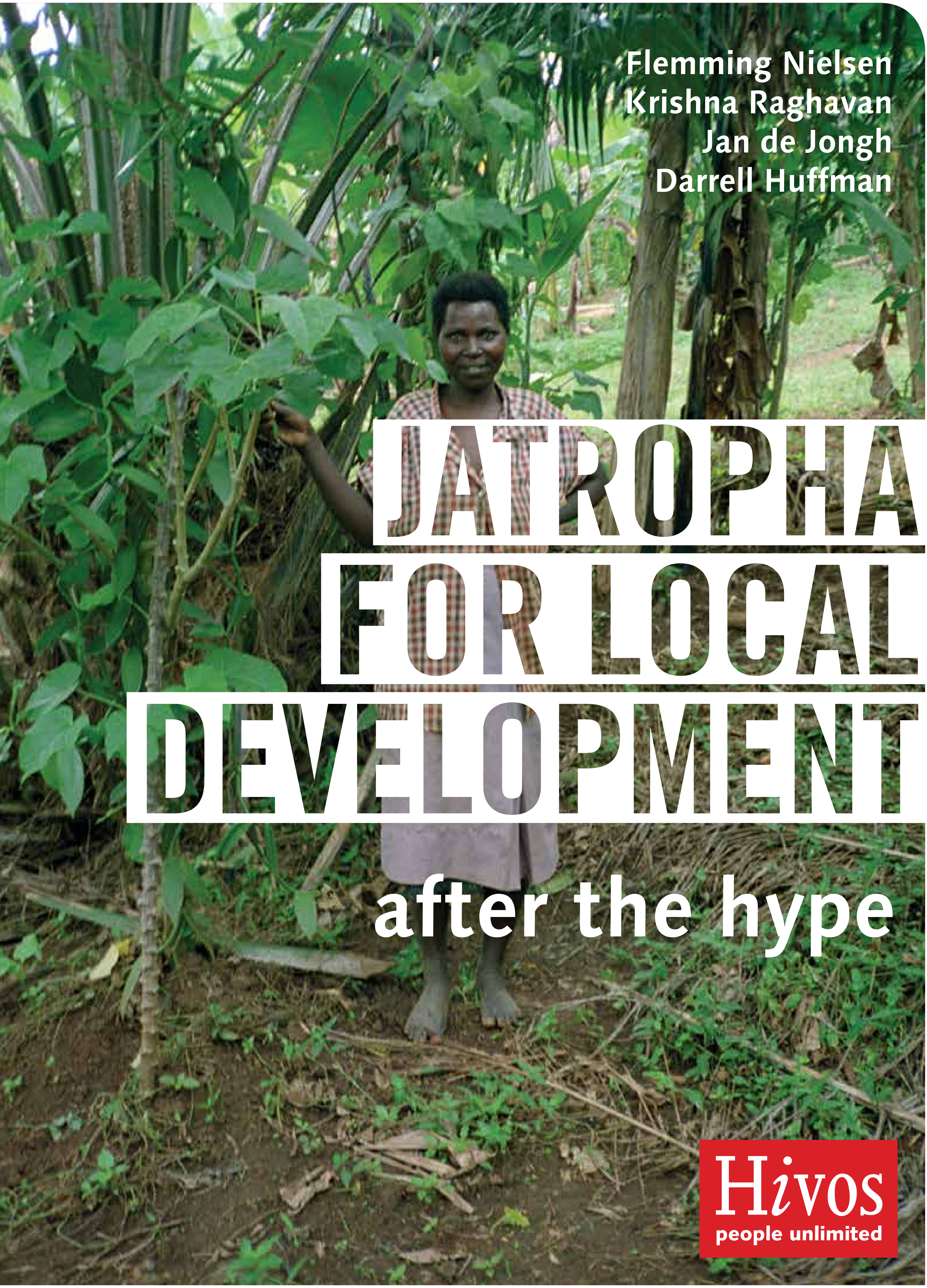
JATROPHA FOR LOCAL DEVELOPMENT

after the hype



Hivos
people unlimited

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About Hivos

Hivos is a Dutch non-governmental organization, founded in 1969, inspired by humanistic values. Together with local organizations in developing countries, Hivos seeks to contribute to a free, fair and sustainable world in which citizens – women and men – have equal access to the resources and opportunities for their development.
www.hivos.org

About FACT Foundation

FACT promotes sustainable biofuels and bioenergy for local communities in developing countries, by providing knowledge and expertise on biofuel implementation, by field testing innovative biofuels and by giving specialist advice on demand.
www.fact-foundation.com

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CONTENT

INTRODUCTION

Over the last few years Hivos has engaged in various pilot biofuel programmes, mostly involving *Jatropha curcas*. These programmes are intended to provide additional cash income for the farmers who grow the crops and may have additional features such as adapting engines, converting the pure plant oil into biodiesel, or even wider goals such as providing the community with renewable energy or dynamising the local economy.

Biofuels have been widely criticised for several reasons, such as displacing food crops and thus reducing food security and possibly food sovereignty, land grabbing, causing large-scale deforestation or clearing of natural vegetation, pushing small-scale farmers into exploitative labour relations or contract farming with large companies, etc.

Being aware of these criticisms, Hivos established criteria to be fulfilled before engaging in biofuel projects. It also decided that no new pilots would be started before more insights into the outcome of these pilots were obtained. In order to assess its first experiences with biofuels, Hivos conducted a meta-evaluation of all six of its biofuel programmes. This study examined whether the introduction and processing of biofuel crops have contributed to the local economy and brought the farmers the expected additional income or whether, conversely, the introduction of these crops has resulted in negative unintended consequences whereby communities are actually worse off than before.

The meta-evaluation brought many insights, but also evoked many questions. For example, if small-scale biodiesel production is not financially feasible now, at what international oil price would it become so? If Jatropha production yields are low now, can we expect them to rise in the future? What would have to be done in order to achieve that? Or would we need to opt for a more diverse approach including other (food) crops? Would farmers be more interested in the crop if returns on labour were better, e.g., if shelling machines were available? It was decided to research some of the most crucial of these questions in greater depth and bring the outcomes together with those from the evaluation in a publication focusing on the benefits for small-scale Jatropha producers and processors, and elaborating the prerequisites and strategies for maximising these benefits.

BACKGROUND

The latest Jatropha hype is the third time Jatropha curcas has received attention as an energy crop. The first time was during the Second World War when local shortages of fossil fuel drove an interest in locally-produced alternatives. In Madagascar, Cape Verde and Benin, biofuel was produced from Jatropha (Foidl et al. 1996, 79). Jatropha was already being cultivated at these and other places for soap production, but by the 1950s it was outcompeted by other feedstocks (Brittaine and Lutaladio 2010, 13). At its peak, 16% of the cultivated land of Cape Verde was under Jatropha and contributed up to 60% of its agricultural export value (Heller 1996, 34).

The second time was in the 1980s when high fossil fuel prices again made Jatropha interesting as a biofuel. Development organisations initiated a number of projects in developing countries, including Nicaragua (Foidl et al. 1996), Cape Verde (Wiesenhütter 2003), India (Patil and Singh 1991) and Mali (Henning, Sidibe, and Sanakoua 1994). However, fossil fuel prices dropped rapidly in the following years, to below $10 US, making practically any alternative energy source unprofitable. During the 1990s, most Jatropha projects were abandoned (Mirco 2012, vi).

Around 2004, high oil prices led to the third Jatropha boom. This time it was driven by private companies, with some NGO and government involvement. The scale was massive, with Jatropha cultivation being initiated throughout the tropics under very diverse conditions. As with the previous booms, oil prices dropped and undermined the profitability of Jatropha.
However, even if oil prices had remained at a high level, many of the now-defunct Jatropha projects still could not have been saved. Jatropha was promoted in areas that are not suitable for the plant. Even where it did grow well, a host of other problems occurred.

An important difference to earlier times was that the development paradigms had changed, with less investment expected from governments and more from the private sector. However, the expectation that the private sector would quickly pick up breeding, seed supply, extension and processing to support smallholders never materialised, leaving farmers without proper extension, without quality seeds and with no place to sell their harvests.

For private plantations, Jatropha's long gestation period, unrealistic yield expectations combined with dropping fossil fuel prices, and the financial crisis have formed a lethal cocktail. Currently, a handful of international private companies remain active in Jatropha breeding and development. Some plantations are still operating, as are smaller cooperatives and a few NGO-supported projects.

Around 2008, public opinion turned 180 degrees from initial wide support to almost universal antagonism. Soaring food prices in 2007-2008 led to social unrest in several countries. The popular explanation was that land being converted from food to biofuel production caused a food shortage. This was supported by a World Bank Working Paper (Mitchel 2008).
The influential paper by Searchinger et al. (2008) amplified the ongoing backlash with its conclusion that due to indirect land use change, both corn and cellulosic ethanol increase carbon emissions as compared to gasoline. The premise is that converting land in, for instance, the US, from food to biofuel production results in land being cleared elsewhere to produce the food. In the public debate, there was rarely any distinction made between corn ethanol and other biofuels or between different modes of production.

The single factor explanation of the food crisis has not stood up to further scrutiny and the consensus is now that it was a perfect storm of many factors, with biofuels not playing the main role (Headey and Fan 2010). The one biofuel program with some effect on food prices was the American bio-ethanol program where corn is used for ethanol production on a large scale. However, by the time more solid research came out it hardly mattered as the debate mainly stayed within professional circles and rarely made it into the popular press.

By 2010 development organisations had almost completely pulled out of biofuels, both because most Jatropha projects had not lived up to expectations and due to a swing in public opinion: even projects that showed promise were not able to raise funding to continue.

Some estimate the latest Jatropha hype cost around $400 million US (Hawkins and Chen 2012, 4). Around 900,000 ha were planted globally – most of it on land unsuitable for Jatropha (Brittaine and Lutaladio 2010, 12).
Research programs on Jatropha only gained momentum around 2008 and an increasing number of articles have been published during the last few years: Worldcat.org lists 1,042 publications on Jatropha for 2012, up from 42 in 2000. Unfortunately, there are not many places where this new knowledge can be applied.

Surprisingly, the international agricultural research centres (CGIAR) have participated in very little Jatropha research. It appears that publicly-funded Jatropha research is declining again.

Many of the advances in Jatropha production over the coming years are likely to be from the handful of international companies that specialise in Jatropha breeding and agronomy. They focus on mechanised plantations where there is a big profit potential if the yield per hectare can be improved and the press cake be used as fodder. In many cases, this does not coincide with the needs of smallholders.
The decline in publicly-funded research means that progress in smallholder Jatropha production is likely to be slow over the coming years. Smallholders are therefore largely left to their own devices, experimenting as they go along.
New projects are being planned by private investors, but generally on a smaller scale than a few years ago. At least one government (Sudan) is currently planning new large-scale Jatropha cultivation.

For other crops that have been cultivated continuously for decades or more, significant knowledge, skills, and adapted planting material emerge. However, the interrupted history of Jatropha cultivation has prevented this progression. As a result, Jatropha is for all practical purposes still a wild undomesticated plant where even very basic knowledge like yield and productive lifespan is highly uncertain.


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WHY JATROPHA FOR DEVELOPMENT?

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The focus of this publication is on systems where Jatropha is integrated into smallholder farming systems to provide energy and other services locally.

Biofuel plantations set up by investors from outside the local area with the goal of supplying international markets are not covered. Such systems have very different dynamics and impact.

Jatropha can substitute for fossil fuels that would otherwise be bought with cash earned from selling crops or animals. This statement highlights the often-overlooked fact that farmers already grow crops to provide energy services. In most cases, this is not obvious because it is intermediated by two markets: that for crops and that for fossil fuel.

Farmers sell crops to pay for transport, for electricity if they are connected to a grid, for paraffin for lamps, for milling etc. Farmers also grow fodder for draught animals. For example, a century ago, temperate Europe and North America used 20% of the agricultural area for oats for feeding draught animals (Gressel 2008, 247).

A recent study covering sites in Kenya, Tanzania and Ethiopia found that households on average used 15 to 20% of their income on direct purchase of energy products such as firewood and kerosene (Ehrensperger, Portner, and Kiteme 2012, 5). This is already a significant amount but is only a part of the energy costs incurred. For example, part of the cost of transport or of milling of crops goes towards fuel costs.

Does it make sense for farmers to grow Jatropha to provide energy and other services directly? Are they better off selling other crops and purchase energy services as they have been doing till now? This is ultimately up to farmers to decide.

Jatropha is just one of many biofuel crops. However, compared to many others it has requirements that make it suitable for integration into smallholder agriculture:

All farmers grow crops to pay for energy services; they sell crops in the market and buy kerosene for lamps, pay for transport, fuel for water pumps and mills etc. Large agricultural areas are used for producing fodder for draught animals.

By switching to Jatropha cultivation, energy and other services can be provided locally.

Photo 1: Better access to energy services is essential for rural development. An irrigation pump in Mozambique

From a development perspective, Jatropha is interesting because it has characteristics that make it suitable for cultivation in non-mechanised farming systems in relatively marginal areas. These areas typically do not benefit from many of the new advances in agriculture and therefore currently have few options for improved livelihoods.

At the same time, these areas have the most limited access to modern energy services, which are widely recognised as essential for development. Lack of energy services impedes progress in health, education, agricultural productivity and local value creation. Connecting remote areas to national electricity grids is expensive and happens at a very slow pace: the number of people without access to electricity stood at about 1.6 billion in 2001 and is expected to still be as high as 1.2 billion by 2030. At the same time, the number of people relying on traditional biomass for cooking, light and heat is actually increasing (Mirco 2012, 9). The potential development impact of a decentralised energy solution is therefore huge.

Photo 2: Generator powered by Jatropha oil. Bilibiza, Mozambique.

Photo 3: Women Farmers sell crops to pay for energy services. Here smallholders harvest cotton. Jatropha can provide local energy services directly.

METHODOLOGY

The main questions addressed in this publication are:

- Under what circumstances is it beneficial for smallholders to cultivate Jatropha to provide energy and other services locally?
- What are the options for making Jatropha cultivation more beneficial to farmers?
- What changes can we expect in Jatropha value chains for smallholders over the coming five years?

The first question was also on the agenda at the beginning of the most recent Jatropha hype: there was limited field experience and research, available from just a few locations. Data was extrapolated to other localities, yield projections and ex-ante cost-benefit analyses were made, and these supported the notion that smallholders throughout the tropics stood to benefit from Jatropha.

After the hype subsided it became clear that things had not played out as planned, and most Jatropha activities have since failed. The conclusion many have drawn is that Jatropha is not useful to anybody.

However, it would be a mistake to make this assumption. There is still strong evidence that Jatropha has a niche. We should learn from the failures and not throw the baby out with the bathwater, as the saying goes. The failures of the past years provide many insights into where and under what circumstances Jatropha can play a role; and what it will take in terms of support, infrastructure, markets etc., in order to make it work.

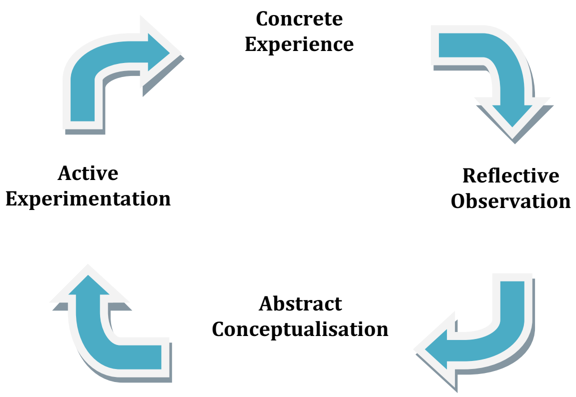


Figure 1: Kolb's cycle of experiential learning (Kolb 1984).

What we are witnessing is part of a normal learning cycle as shown in Figure 1 (Kolb 1984). The learning cycle perspective was ignored by many who viewed Jatropha as something that just needed to be rolled out to the farmers. The result of this was that too little attention was given to generating solid data, learning and documentation. Considering the scale of the recent Jatropha hype, surprisingly little solid evidence has been generated.

In this publication, we focus on the 'reflective observation' and 'abstract conceptualisation' points in the learning cycle. We do so by combining our own experience of Jatropha value chain development, with reviews of experience from other projects published in project documents, presented at conferences or gleaned from conversations. Alongside this, we have combed through thousands of pages of scientific literature.

All of the findings presented are supported by detailed references, so the reader can check our work. In cases where important reports and papers in our assessments have serious flaws, we explain what the flaws are. Often this is done in footnotes, in order to avoid interrupting the flow of the text. In line with standard academic practice, examples that have no references are based on our own experience and observations. Jatropha value chains are a big topic and we therefore start by identifying the niche where Jatropha looks promising in the chapter "The Niche for Jatropha".

After having established where and under what circumstances Jatropha can be viable, the chapter entitled "Increasing the Farm Gate Price of Jatropha Seeds" looks into options for improving the processing of Jatropha to provide more local products and services as well as providing higher income.

The chapter entitled "Reducing Farmers' Production Costs" looks at options for increasing the benefits of Jatropha to farmers by reducing the production costs on the farm.

The risk issues that arise from using a poisonous plant like Jatropha are covered in the chapter "Health Issues". This chapter cuts across the full value chain from seed handling to safety of final products like soap.

Finally, we conclude by summarising the findings of the previous chapters and giving an outlook for the coming five years.

Sources of information

Each of the different types of sources we have used comes with its own specific problems:

> *The role of private companies in Jatropha research is increasing as NGOs and public organisations pull out. This reduces transparency and access to new innovations for smallholders.*

Photo 4: Participatory exercise where farmers document how the labour demand of Jatropha fits with local farming systems.

Commercial companies

Commercial companies closely guard their work. The only data they tend to publish is highlights, i.e. selected good results. Poor results are not shared because they can threaten a company's market position. Even the very little specific data that is released is often missing important contextual information.

Advocacy groups

Some environmental advocacy groups have tried to substantiate their campaigns with various research papers that in some cases have become widely cited. However, close reading of several of these papers reveals that the authors have been cherry-picking their information, i.e., including only papers or paragraphs which support their agenda. In some cases, we have seen that things have been taken out of context or been misrepresented[1].

> *Jatropha cultivation by semi-subsistence farmers in Africa is poorly documented. This is problematic since it is a main niche for Jatropha for local development.*

Development organisations

Reports from development organisations are the main source of information on the performance of Jatropha under smallholder conditions. However, as mentioned above, Jatropha was generally viewed to be something that just needed to be rolled out to farmers, so little was done to generate solid data that could be used to improve the Jatropha value chain. In most cases, data reporting is limited to simple statistics like the number of farmers, number of Jatropha plants and litres of oil or biodiesel produced. In general, projects in Asia and Latin America have been better documented than those in Africa. One reason for this is that African farmers are more likely to operate in a subsistence economy and practise intercropping, which makes it difficult to assess factors such as the cost of weeding, the "real" area under Jatropha or the value of the crop substituted by Jatropha – figures that are often available from Indian projects.

Formal research

As mentioned in the background chapter, research only picked up after most Jatropha cultivation had started. Instead of being integrated R&D, most research that has generated hard data has been on-station and laboratory research. The conditions there are so different from the farmers' fields that the data is of limited practical value.

1. An example: In Mozambique, one of the authors (F. Nielsen) arranged a research project for a student to collect data on insects in Jatropha. Forty-one different insects were observed (Gagnaux 2009). Most of them are probably harmless to Jatropha; some are useful as pollinators and some are pests. However, this was not investigated so we don't know the numbers. Still the SWISSAID study "Jatropha! A socio-economic pitfall for Mozambique" (Jatropha Alliance 2009) used the study to argue that there are "forty pests" and probably more in Jatropha. We contacted the authors of the report but never heard anything back. Friends of the Earth first excluded Jatropha from their campaigns against biofuels but later they included it (Mirco 2012, 44) and produced a number of "scientific reports" to support this stand. One of them is named "Jatropha, money doesn't grow on trees" (Christine Pohl 2010). It uses the misguided SWISSAID study to prove there are immense pest problems in Jatropha. We contacted Friends of the Earth but never heard anything back. We have not experienced this lack of response from development organisations, government institutions or private companies.

THE NICHE FOR JATROPHA

Just like any other crop, Jatropha has certain niches where it performs well and is attractive compared to the alternatives. In this chapter we combine the latest knowledge about the agro-climatic requirements of Jatropha and the experience gained from Jatropha cultivation in different regions and under different farming systems.

The experience of the last years shows that the major factors determining success & failure of Jatropha cultivation for local development are:

- **Agro-climatic conditions:** Many failed attempts to cultivate Jatropha have taken place at locations with inappropriate conditions for Jatropha, resulting in high mortality rates, low yield and excessive pest and disease susceptibility. It is estimated that more than eighty per cent of all Jatropha has been planted at unsuitable locations (Hivos Expert meeting 2012).
- **Labour costs:** Jatropha is relatively labour-intensive and the options for mechanisation are at present limited. In areas with high labour costs Jatropha is not competitive.
- **Land costs:** The economic yield per hectare of Jatropha is low and it is therefore best suited for areas with low land costs, i.e. areas with no land constraints.
- **Alternative income options:** Like any other crop, the attractiveness of Jatropha depends on the alternative income options.
- **Prices of imported goods:** Our focus is local development through substitution of imported goods for Jatropha-derived products like engine fuel, soap, fertiliser and lamp oil. The higher the prices of the products being substituted, the more attractive Jatropha is.
- **Environmental impact:** The issue of perceived environmental impact has been an important factor in both the initial hype and the ensuing collapse of Jatropha, by influencing funding and investment available for Jatropha cultivation and for policies like blending targets, extension services and credits.
- **Seasonal fit with cropping systems:** In non-mechanised farming systems, labour is the limiting factor of production and labour demand fluctuates with the seasons. Jatropha cultivation that does not require work at the same time of the year as other crops is more attractive to the farmers.
- **Multiple products and functions:** It is the combined value of products and functions of Jatropha that determines how attractive it is compared to alternative crops. Examples of products include fuel oil, lamp oil, and biogas from press cake, medicine, and bio-pesticides. Examples of functions are fencing, land demarcation, erosion control and resilience by providing an income source in dry years when other crops fail.

In the following sections we will discuss the latest research and experience related to these factors before drawing conclusions on where and under what conditions there is a niche for Jatropha.

The Right Agro-Climatic Conditions

Most of the Jatropha cultivation has been initiated in areas without the right agro-climatic conditions for the crop. As a result mortality is high, yields are low and expenses for pesticides – and sometimes irrigation – are high.

Recent work by Trabucco et al. (2010) has produced the global Jatropha yield map in Figure 2. In our assessment the map is quite reliable in reporting the relative performance of Jatropha at different localities. However, the absolute yield figures in the map are highly uncertain[2]. The company Quinvita has produced a similar map. It is not available to the public but is said to be very similar to the one by Trabucco et al. (Henk Joos and Vincent Volckaert, pers. comm.).

2 The map is based on herbarium data coupled with agro-climatic data to produce a "probability of occurrence" map. Due to the relatively high number of samples and the good experience with this method for other plants and animals it is likely that the map gives a quite precise depiction of the spatial suitability for Jatropha cultivation. The yields provided in the map are however more uncertain. They are simply arrived at by multiplying the probability of occurrence with a maximum yield of 5 t/ha. Both the underlying assumption of linear relationship and the 5 t/ha max yield are uncertain. The latter is based on the review by Achten et al. (2008) who clearly state that the 5 t/ha figure is just one figure arrived at by some researchers, while others have arrived at figures ranging from 1.5 to 7.8 t/ha. The absolute yields figures depicted in the map are therefore uncertain.

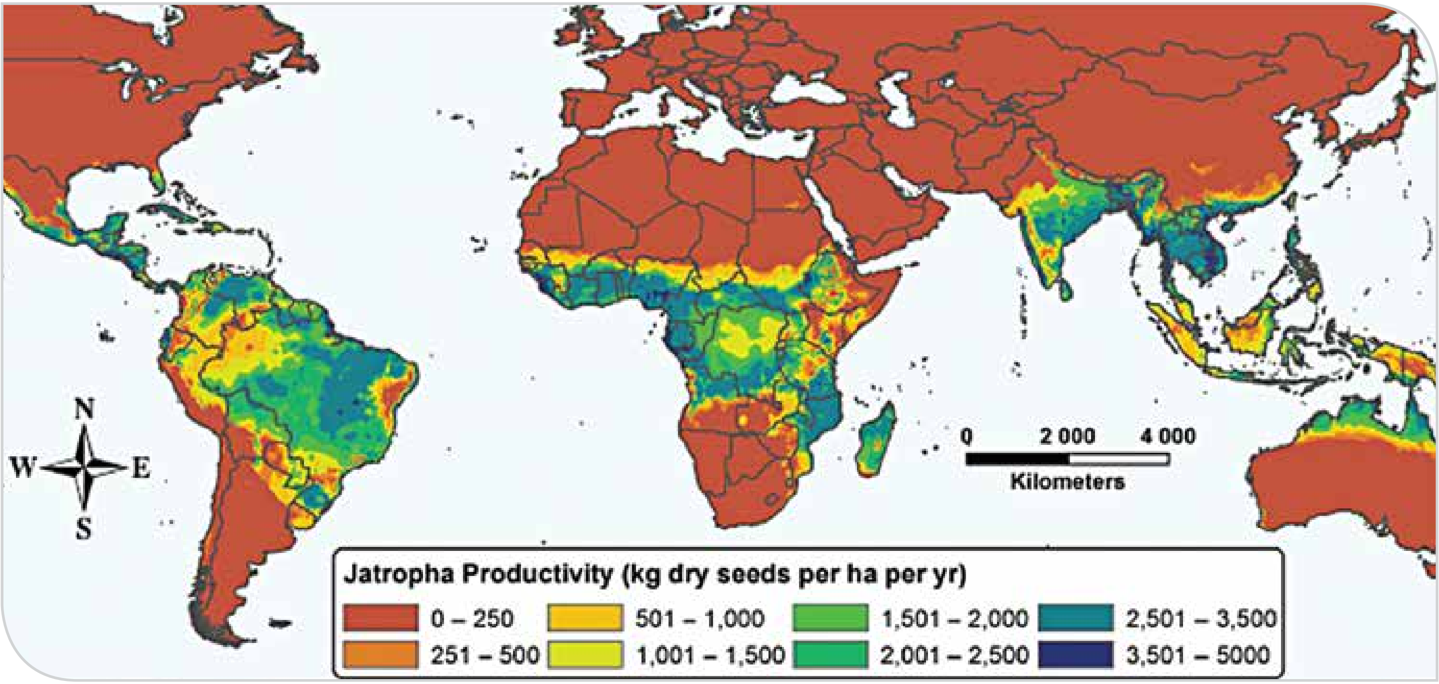


Figure 2: Estimated Jatropha productivity (kg dry seeds ha-1 yr-1) for present climatic conditions (Trabucco et al. 2010, 146)

An interesting finding that is not obvious from the map is that a distinct dry season is required for high yields, and that the temperature in the hot season should be between 35 and 40°C. The cold season should be warmer than 8-9°C and the annual mean temperature 25-26°C.
There are limitations to a map of this resolution: the local conditions may differ from the average conditions depicted in the map, e.g. in mountainous areas the conditions in valleys and at high elevation may differ significantly. Furthermore, farmers may modify the environment through irrigation, water harvesting and other practices.

Many projects have been undertaken in areas that are not suited to Jatropha. This includes major plantings in India and China.

In Kenya, the Jatropha data sampled in the influential study by Lyama et al. (2009) are mostly from areas unsuitable for Jatropha according to Trabucco et al. Unfortunately that study is regularly used to prove that the yield of Jatropha is too low, and the yield and production cost figures from the study have been used in various studies and articles (e.g. Eijck, Smeets, and Faaij 2012).

Most Jatropha has been planted in areas unsuitable for the crop, resulting in high mortality, low yields and extra costs to irrigation and pesticides.

A more detailed assessment of the suitability of Jatropha cultivation in parts of Kenya has since been undertaken (Tinguely 2012) and reaches conclusions similar to Trabucco et al. Figure 3 illustrates the micro-variation that is hidden in the more general maps. However, this map is based on modelling and has not been verified with field data so it is not possible to assess the quality. The global yield model by Trabucco et al. has been compared to field data but includes just a few small data sets from a few locations. In both cases, the limitations are due to the lack of reliable yield data for Jatropha.

Tanzania is another country with much Jatropha cultivation, but with limited suitable areas for this crop. Only 8% of the marginal land has conditions suitable for Jatropha (W. Achten 2010, 150).

Even though the knowledge about the agro-climatic requirements for Jatropha cultivation has improved in recent years, it is only sufficient to exclude obviously inappropriate areas.

We have a general understanding of where Jatropha can grow but only trial plantings can reliably tell us what yields to expect.

While some areas can be identified as suitable for Jatropha cultivation with a high degree of certainty, this is often not the case: models can give an indication but cannot substitute for test planting. Even with further refinements of the models this is likely to remain the case; experience with other crops shows that it is not possible to reliably predict suitability and, in particular, yield in smallholder agriculture using models and research station data alone.

The fastest way to improve the knowledge of which areas are suitable is to allow farmers to experiment with Jatropha and ensure appropriate measurements, recording and data sharing. When this method is followed, it is important that farmers understand the uncertainties involved and are not misled into taking unjustified risks.

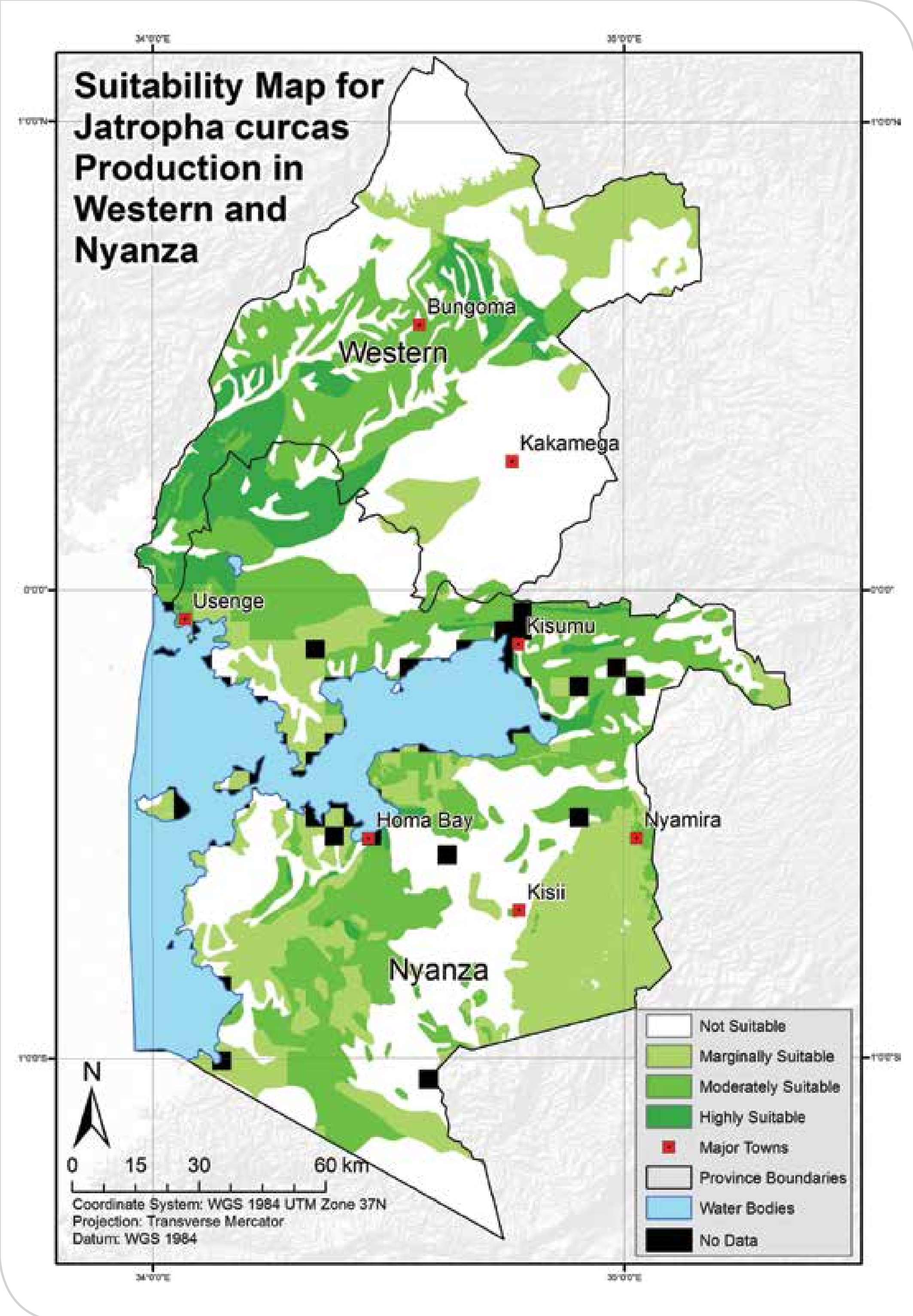


Figure 3: Suitability map for Jatropha curcas production in Western and Nyanza province in Kenya (Tinguely 2012, 61).

Low Labour Costs

The major production cost in the current Jatropha cultivation systems is labour for harvesting and de-hulling. There are physical limitations to how many kilograms of seeds can be harvested manually per working hour, so productivity is similar between regions.

Until now the focus of Jatropha value chains has been on only one product, namely Jatropha oil for fuel to substitute fossil diesel. In order to be viable, the Jatropha oil or biodiesel cannot be priced above the fossil diesel, which sets strict limits on the maximum price that can be paid to farmers.

These two constraints mean that at present Jatropha is only profitable where labour costs are low. For example, it was found that in Bajo Mayo, Ecuador, farmers earned less than half of the minimum salary when cultivating Jatropha without any mechanisation: it takes $7 to $9 US in labour costs to produce seeds with a value of $3.40 US (Veen 2011, 15).

In Mozambique, labour costs are lower and it was found that the daily income of fast-working farmers was about double that of the common day rate for manual labour. The slowest farmers earned about two-thirds of the rate for manual labour (Nielsen 2009a).

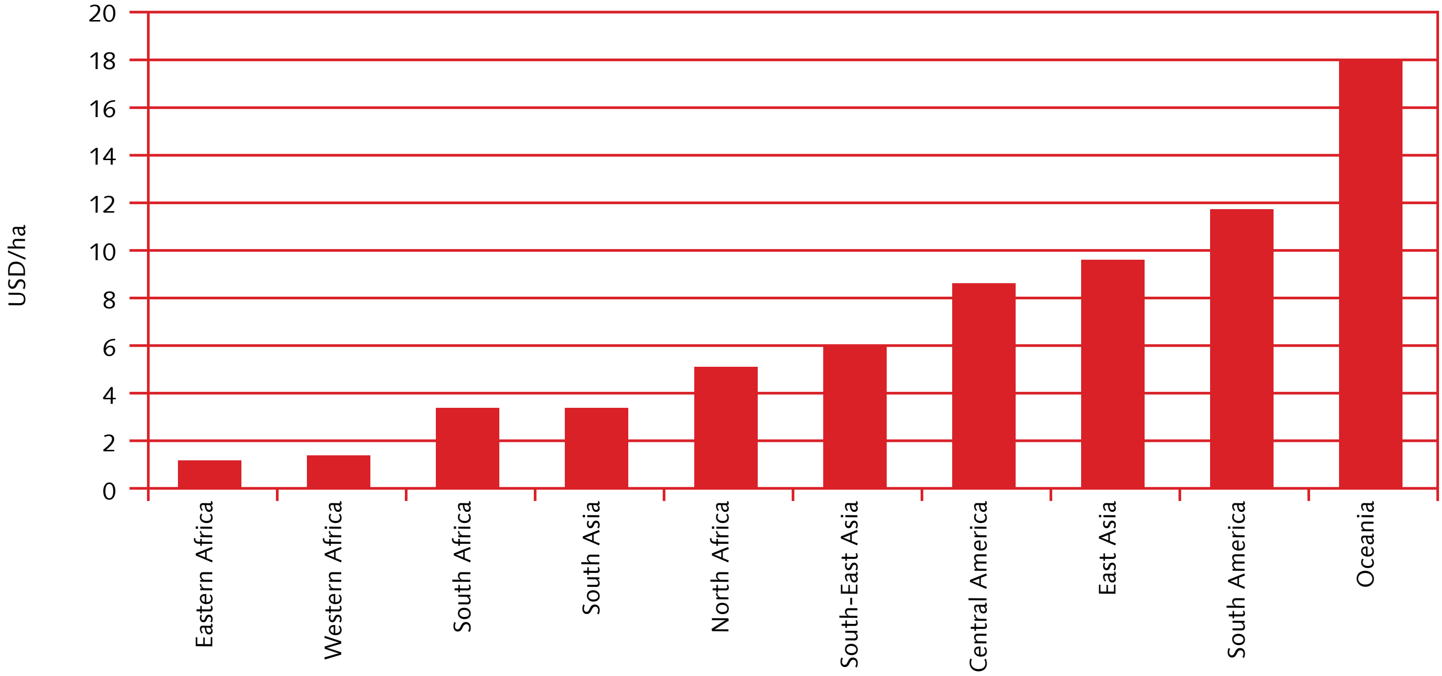


Figure 4: Regional labour costs in biomass energy production (based on average costs in scenario A1, table 3 in Hoogwijk et al. 2009, 34)

The low labour costs in Africa (excluding South Africa) gives the continent a significant comparative advantage over all other regions.

Eco-Carbone found that in Mali a farmer can earn the minimum salary by selling 15 kg of Jatropha seeds per day, whereas in Vietnam twice as much is required (Degail and Chantry 2012, 10).

Hoogwijk et al. calculated regional labour costs for biomass energy under four scenarios (Hoogwijk et al. 2009). The data are confirmed by a recent survey of Jatropha projects that include labour costs from 84 projects (Wahl et al. 2012, 47). The Hoogwijk data are used here because they are more detailed. From Figure 4 it can be seen that East and West Africa have a significant advantage compared to other regions.

South Africa has significantly higher labour costs than the rest of the continent. Borman et al. (2012) analysed the economics of Jatropha cultivation there and found that labour costs are too high for Jatropha to be profitable. In contrast, they found that in India and Zambia a financial break-even point is achieved with just 470 to 660 kg/ha. Below that yield, too much time is spent on harvesting.

The regional data are crude figures. In practice, there are salary differences between countries in a region and between localities within a country. Rates paid at the informal markets vary tremendously and are difficult to assess reliably. In the countryside, day rates vary with the season. Due to a lack of real data official minimum salaries are often used in cost-benefit analysis. This makes sense for plantations as they generally obey the laws but at the informal labour market of smallholders salaries can be very different.

For smallholders that rely on family labour, it is the opportunity costs that count and not directly the day rate for hired labour. In many countries, the majority of smallholders earn below the official minimum wage.

This variation can have a significant impact on the viability of Jatropha. For instance, the case from Mozambique cited above is from a remote area where the going rate for labour is below the government's minimum salaries, thus making Jatropha even more attractive to farmers than the numbers indicate. In other parts of Mozambique with alternative income options, Jatropha is less attractive. This should be considered both when planning Jatropha cultivation or when up-scaling of successful projects is proposed.

That labour constitutes the main cost in Jatropha production opens up the possibility of creating rural employment. An economic study of potential biofuel production in Mozambique estimated that Jatropha plantations can create jobs for 271,000 labourer (Arndt et al. 2009, 12). A global economic study estimated that the direct employment benefit is one job for each 9 ha in low input systems and one per 3.5 ha for intermediate input systems (Franke et al. 2012, 96). Other studies differ significantly in their assessment of the employment benefits (Gasparatos et al. 2012, 30).

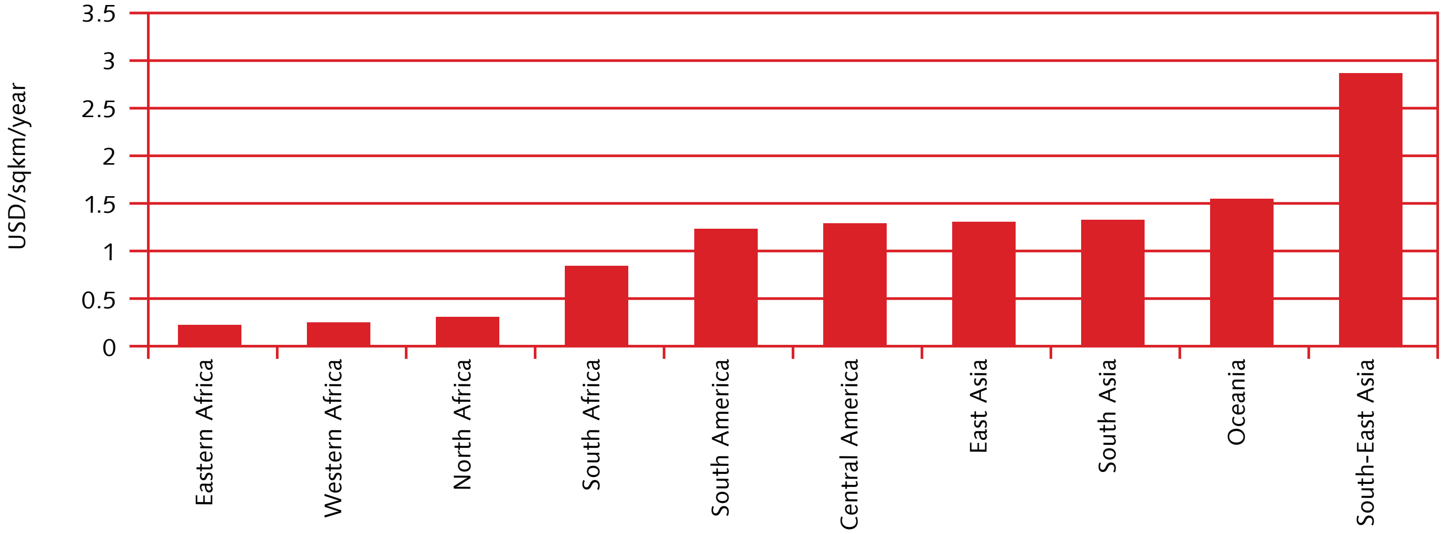


Figure 5: Regional land costs in biomass energy production (based on average costs in scenario A1, table 3 in Hoogwijk et al. 2009, 34)

The low land costs in parts of Africa give the continent a significant comparative advantage over other regions.

There are several ways to break out of the labour constraints of current production systems, e.g., productivity can be improved with mechanisation, and the value of Jatropha seeds can be increased if multiple products are produced instead of the current one only. This is the focus of the chapters "Increasing the Farm Gate Price of Jatropha Seeds" and "Reducing Farmers' Production Costs".

Areas with abundant unused land available are required for Jatropha production because the cost of land is low there – not because more land is expected to be cultivated.

No Land Constraints

With the profitability of current Jatropha production systems being constrained by labour costs, even low land costs can make Jatropha unprofitable. Only areas with low or zero land costs are therefore currently viable for Jatropha cultivation. These conditions only occur where land for cultivation is abundant.

Again a comparison between regions shows that East and West Africa have a significant comparative advantage over other regions. In Figure 5 it can be seen that Asia and the Americas have average land costs for energy crops that are about six times larger than those of East and West Africa.

The regional averages hide huge variations, from land costs of around zero in parts of Mozambique (which cultivates just a small fraction of its agricultural land), to high costs in places like land-scarce Kenya.

In areas where Jatropha has performed relatively well, like Mali and parts of Mozambique (Prakash 2012), land is allocated for free by local authorities. In areas where Jatropha hedges replace hedges that were not used productively, the opportunity cost of the land is zero (Ehrensperger, Portner, and Kiteme 2012, 8).

Competition for land between biofuels and food has received much attention; negative impact has been documented in, for instance, Tamil Nadu (Ariza-Montobbio and Lele 2010) where the farmers earned less from Jatropha than they did from the crops it replaced. Farmers responded by stopping Jatropha cultivation, and since the investment in Jatropha was limited the loss was small. This is, in other words, no different from normal farming operations where farmers regularly adjust their crop mixture in response to own needs, markets, weather changes and availability of inputs. The main issue in the Tamil Nadu case is that farmers were led to believe that they were guaranteed higher yields from Jatropha than what they eventually achieved.

Where land is abundant and credits are made available, it is possible for farmers to expand the area under cultivation because they can overcome the labour constraints by hiring farm labour from elsewhere and investing in mechanisation. These conditions were present in Brazil where the government started promoting cultivation of Jatropha and Castor (*Ricinus communis*) by smallholders in marginal areas as part of the PNPB program from 2004[3]. One impact study that has received some attention concludes that biofuel production has led to reduced food security and deforestation (Finco and Doppler 2010). However, the study is, in our assessment, fundamentally flawed[4] and the data does not support the conclusions reached.

All farmers cultivate crops to provide energy services. Crops are sold to be able to pay for energy services like electricity, candles, fuel, batteries, transport and milling. When switching to energy crops, the farmer is substituting those energy crops for crops destined for sale. Expansion of the cultivated area is not expected.

One issue often overlooked in the land for food versus fuel debate is that farmers already cultivate crops to cover their energy needs. Food and cash crops are sold to be able to pay for energy services like paraffin for lamps, batteries for radios, transport and milling of grains. Substituting energy crops for crops which would have been sold to buy energy services is a minor change. Since the farm size in land-abundant areas is limited by the labour and capital available to the farmer, the switch to energy crops is unlikely to change the area under cultivation locally.

For farmers who used to sell part of their food crops to raise cash, the effect on resilience can be positive because the price of food and energy crops is not correlated to the same extent as different food crops. For instance, a regional bumper harvest may lead to a drop in the prices of all food crops but will not affect the price of transport fuel and therefore bio-energy crops.

However, since Jatropha is non-edible, crops intended for sale no longer provide a direct food reserve in case of low food crop yields. Instead, the farmer depends on markets for selling fuel crops and for purchasing food. Whether this is positive or negative depends on the market conditions, among other factors.

Energy crop prices follow the fossil fuel price closely. Often, this is different from food crop prices. Farmers producing for both markets can therefore be more resilient to market fluctuations.

The most comprehensive assessment of these trade-offs has been undertaken by FAO for Tanzania ('FAO, The BEFS Analysis for Tanzania' 2010). This study concluded that farmers can gain from switching to biofuel crops and that the yield of food crops is likely to increase because more money becomes available for buying farm inputs. The study found no negative trade-offs at the national level. One reason is that most of the biofuel crops are expected to replace lower-paying non-edible cash crops.

We are not arguing that the land for food versus fuel debate is bogus. It is important to consider the impact on food consumers, climate change, indirect land use changes (ILUC) etc. Also large-scale biofuel plantations will have a different impact than Jatropha for local development. However, these issues are outside the scope of this publication.

The most obvious way to overcome the constraints imposed by land costs is to reduce the land required, e.g. by increasing the yield or by intercropping. If this happens, Jatropha cultivation will become an option for farmers in areas where it is currently unprofitable.

It is often assumed that cultivation of bio-energy crops requires significant expansion of the land under cultivation. However, if bio-energy crops are introduced into smallholder farming systems this is unlikely to happen. In land-abundant areas, the farm size is limited by the labour and capital available to the farmers. If they were able to cultivate more land they would already be doing so. The introduction of a new crop like Jatropha does not magically enable farmers to expand the cultivated area. The reason why land-abundant areas are suitable for Jatropha is not because more land is needed but because the cost of land is minimal.

However, indirect land-use change is still an issue to consider as the crops that are replaced will have to be produced elsewhere, whether by farm expansion or by increased productivity.

3 See: http://www.mme.gov.br/programas/biodiesel/menu/programa/historico.html
4 The study (Finco and Doppler 2010) found that 25% of farmers had cleared forest to cultivate Jatropha whereas the remaining 75% had replaced crops on their existing crop land. Unfortunately, the survey design is flawed as it only sampled energy crop producers and lacks a control group of farmers not cultivating energy crops: the study area was suffering from deforestation before Jatropha was promoted, and the lack of a control group makes it impossible to conclude whether the deforestation by Jatropha-growing farmers was just "business as usual" or indeed accelerated by Jatropha promotion. The study also shows that farmers growing biofuel crops purchase much of their food and concludes that the food security is therefore impacted negatively. Again, there are no data for farmers not growing biofuel crops so this cannot be compared and, even if data were available, factors such as savings and price fluctuations in the market would have to be considered in an assessment of food security. Food security is not the same as food self-sufficiency.

Recent on-farm trials in Tanzania shows that this is possible under some circumstances: in intercropped Jatropha and maize fields the maize yield increased by 66%, thus making it possible to maintain the food production and growing Jatropha without expanding the cultivated area (van de Staaij et al. 2012; Ecofys Netherlands B.V. 2012). Improved agronomic practices played an important role for these results (pers. comm. Ab van Peer).

One caveat to the statement that smallholders in land-abundant areas already cultivate as much land as they can manage is that if Jatropha replaces crops that require more resources per hectare, then a larger area can be cultivated with the same resources. Where annual crops are replaced by Jatropha, this will often be the case and some – but not significant[5] – expansion happens. A better seasonal fit will have the same effect (see the section "Seasonal Fit with Cropping Systems").

Significant expansion of the cultivated area with an energy crop is only likely to happen if plantations are established with capital from outside. Significant subsidies to farmers could have some impact but this is a less likely scenario[6].

Remoteness and Lack of Alternative Income Sources

The more remote an area is, the more attractive it becomes to cover the local energy consumption with locally-produced energy.

Transport cost means that cash crops sold to outside markets fetch a lower price and imported goods like fuel are more expensive.

Remote areas offer few opportunities for paid labour or other income sources: in Madagascar, Bünner (2009) showed that farmers found it attractive to work on a Jatropha plantation even when salaries were lower than the going rate for other unskilled wage work, because there was simply no other work available.

However, remoteness also makes spare parts for oil expellers and other equipment more expensive. A lower education level and lack of people skilled in operating and maintaining mechanical equipment increase the operational expenses and reduce the longevity of equipment. The effect of these factors and remedies are covered in detail in the chapter "Increasing the Farm Gate Price of Jatropha Seeds".

High Prices of Substitute Products

High prices on the products being substituted by Jatropha naturally favour Jatropha cultivation. Because the focus so far has been on replacing fossil diesel, the local diesel price has a major bearing on the profitability of Jatropha.

5 As discussed elsewhere in this publication, the options for mechanisation are limited and the labour input per hectare is therefore substantial; this limits the expansion that a switch from annual crops to Jatropha can cause. Secondly, the impact is diluted because Jatropha is only one small part of the crop mixture on smallholder farms.
6 Only countries with sufficient resources can afford significant subsidies in the long run. Brazil is an example. However, such countries are generally not suitable for Jatropha production because labour and land is too expensive.

The local fossil fuel price can deviate significantly from national figures and prices in cities. In Northern Mozambique where the FACT/ADPP Jatropha project is located, fossil fuel costs up to double the price charged in the nearest city. Borman (2012, 10) analysed the economics of Jatropha production in India and Zambia. In the latter case, the high local diesel price contributed significantly to the profitability of Jatropha.

Where soap, bio-fertiliser, bio-pesticide and other products are produced the same logic applies.

No Negative Environmental Impact

The major environmental concern in connection with Jatropha cultivation is currently the carbon debt incurred when converting land into Jatropha fields. This has no direct effect on the farmers – but indirectly it is crucial because it feeds into the international debate about climate change and energy policy, which influence allocation of development aid and energy policies, including blending targets.

A recent study found that in sub-Saharan Africa, converting mosaic cropland in arid steppe and temperate zones with hot dry seasons does not trigger a carbon debt. In South Asia, Jatropha yields of 3.1 to 4.6 t/ha are required to repay the debt within 30 years, whereas yields of 5.8 t/ha are necessary in the tropical savannah zones of South America (W.M.J. Achten et al. 2012).

Other concerns have been raised including the possibility of negative impact on biodiversity and weediness but there is no evidence that they are significant issues. Jatropha was introduced throughout the tropics more than a century ago and there are no reports of weediness of *Jatropha curcas* so far. Sometimes confusion has occurred because other Jatropha species, like the bellyache bush *Jatropha gossypiifolia*, are notorious weeds (Panetta 2009).

CABI warns about the negative allelopathic effect of Jatropha on the germination of other crops[7] and refer to a compendium (Rastogi and Mehrotra 1991) and one article that describes Jatropha as an "obnoxious weed" (Oudhia 2000). However, considering that Jatropha is successfully intercropped with other crops throughout the tropics this is unlikely to be a real issue. It is common for plants produce allelochemicals and the effect is difficult to predict from laboratory tests[8].

7 http://www.cabi.org/isc/?compid=5&dsid=28393&loadmodule=datasheet&page=481&site=144
8 The classical example is Salvia leucophylla which for decades was thought to kill off other plants with allelochemicals identified in laboratory studies. Only when field research was carried out and animal access to the plant was prevented was it shown that it was animals and not allelochemicals which prevented other plants from growing nearby. This very informative story is described in details in Halsey R. W. (Halsey 2004).

Photo 5: Jatropha used to support vanilla in Mukono, Uganda

For the farmers, the major concern may be the human health impact of the poison in Jatropha plants. What happens when press cake is used to fertilise food crops? Is it dangerous to use Jatropha soap? Since these health-related issues are important and have received scant attention so far, we have covered them in the chapter "Health Issues".

Seasonal Fit with Cropping Systems

Farming is a seasonal activity. For manual farming, weeding and sometimes harvesting is the most demanding task and the area that can be weeded sets the upper limit for the area that can be cultivated. The rest of the year the labour is not fully utilised. New crops that demand labour at different times of the year than other crops are very attractive to the farmers.
In most places the planting of Jatropha seedlings takes place just before the rainy season and therefore does not clash with the labour peak at the onset of the rains. This is a common practice in countries such as Mozambique (pers. obs.), Mali, Laos, and Vietnam (Degail and Chantry 2012, 9).

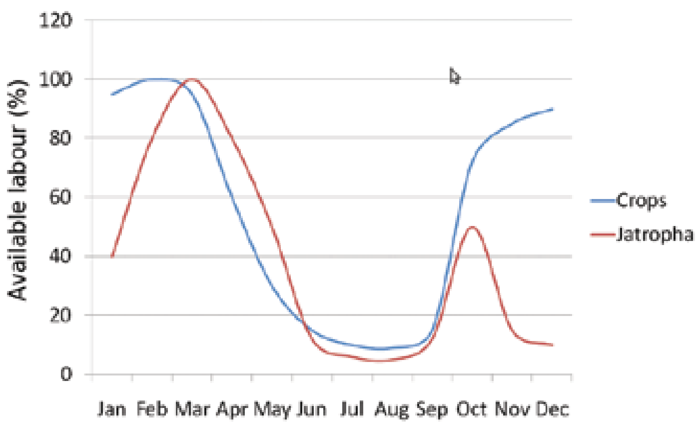


Figure 6: Seasonal labour demand for Jatropha and food crops in Cabo Delgado, Mozambique (Nielsen 2009a)

However, planting is only undertaken once in the lifetime of Jatropha. The seasonal fit of the Jatropha harvest is therefore the main concern.

In Zambia, it was found that the Jatropha harvest season is from January to May which is earlier than the maize harvest. However, it overlaps with the weeding of maize and beans (Prakash 2012).

In Figure 6 the labour demand for Jatropha is compared to that of other crops in Northern Mozambique (Nielsen 2009a). The graphs were drawn in a participatory exercise with farmers who had cultivated Jatropha for several years. The main Jatropha harvest coincides with the harvesting of food crops, which is not ideal. The second harvest at the start of the rains was only observed in some localities. In places with sufficient soil moisture, ripe seeds were available throughout the year in varying quantities.

Farmers were advised to postpone the Jatropha harvest until after all food crops had been harvested, but chose not to do so, the reason being that they find harvesting Jatropha a light task and therefore like to do it several times a day in between harvesting more demanding crops like tubers (Nielsen 2009c). At the Gota Verde project in Honduras, the harvesting of Jatropha also coincided with harvesting of other cash crops. With irrigation it was possible to move the harvest period to a more convenient time (Prakash 2012). However, it rarely makes economic sense to irrigate Jatropha.

In Peru, it was observed that sporadic rainfall resulted in several small harvest peaks spread out over the year (Prakash 2012). In all cases referred to above, farmers prioritised harvesting of food crops over Jatropha.

Multiple Products and Functions

Most Jatropha production has so far focused on only one product, namely Jatropha oil to substitute for diesel in the form of biodiesel or to use directly in modified diesel engines. However, the press cake contains as much energy as the oil and can be utilised in multiple ways. Jatropha oil can also be used for many other products apart from fuel.

Value-added products that have been tested on a small scale include soap, lamp oil, lotions, shampoo, bio-pesticides, bio-fertiliser, biogas and briquettes. Many of them command a higher price than fuel for engines and some are pure value-added products that do not impact the oil production.

Apart from increasing the profitability of Jatropha, the price volatility is also reduced when multiple products are produced and the energy balance improves (Eijck et al. 2010, 79).

Jatropha provides multiple functions on the farm, which is the reason it was used long before it became an energy crop. As hedges, it provides protection against animals and demarcates land. It has a long history as a support plant for vanilla and as a medicinal plant.

As a perennial with a deep tap root it can both reduce surface erosion and restore soil fertility,y by moving nutrients unreachable by crops back to the surface. Water retention and general soil conditions are improved (Brittaine and Lutaladio 2010, 4).

The chapter “Product Diversification” provides an in-depth review of the experience and potential for Jatropha-based products.

A Niche for Jatropha in Rural Africa

Currently, parts of Africa form the area that provides the best global settings for Jatropha for local development.

- The agro-climatic conditions are right;
- no carbon debt is incurred in some climatic zones;
- labour costs are lower than elsewhere;
- Africa is the continent with the lowest utilisation of its agricultural land, so;
- land costs are low; and finally
- the products for which Jatropha can substitute are expensive and in demand locally.

Africa lacks modern energy services more than any other continent. Connecting every remote farmer to the national grid is prohibitively expensive, so decentralised solutions are required.

This conclusion is also supported by the observation that some of the Jatropha cultivation initiated with small farmers in Africa is still operating. One example is the Hivos- supported FACT/ADPP project in Northern Mozambique where the number of Jatropha farmers is expanding and local processing is continuing, several years after the end of support from Hivos and FACT Foundation.

In West Africa, Jatropha cultivation is spreading among farmers associated with the private company Mali Biocarburant. This began within Mali but is now occurring in Burkina Faso and Niger as well, with plans to expand even further (Verkuijl 2012). Some NGO-supported projects also continue but it is difficult to assess their viability once the outside support ends.
Other studies have reached similar conclusions (Eijck, Smeets, and Faaij 2012, 1–2) about Africa having the highest potential. Mozambique is considered one of the African countries with the highest potential for biofuel production (Nhantumbo, Salomão, and IIED 2010, 3).

However, the areas with the highest potential are also very challenging places to establish a new value chain. The education level is lower than elsewhere, making it difficult to find qualified staff to operate presses and other equipment. When people have achieved a certain skill level, many leave in search of better opportunities. The operational costs increase and non-optimal operation and maintenance of equipment reduce its longevity. Infrastructure is poor, making transport expensive and unreliable. The lack of distribution channels, including micro-grids to feed electricity into and gas stations for selling biodiesel, can be challenging.

The remoteness which creates good market conditions for bioenergy also hampers Jatropha processing. Spare parts are difficult to find, and expensive.

How these contradictory forces balance depends on many factors. A more detailed discussion, with examples from the field, forms part of the following chapter.

INCREASING THE FARM GATE PRICE OF JATROPHA SEEDS

Jatropha for local development is an example of a vertically integrated value chain where cultivators, processors and consumers are to a large extent the same people. One may therefore expect that the farm gate price is unimportant as long as the overall value chain is profitable. However, in practice oil-processing facilities are usually organisationally separate units that either pay upon delivery or use a settlement price to calculate the share of the profit each farmer will receive. If other feedstocks are cheaper than Jatropha the press operators have little incentive to buy Jatropha.

The price offered to farmers depends on the value of the products produced from Jatropha and the efficiency of the production.

Unprocessed Jatropha seeds have traditionally been used for candles and the practice can still be observed in poor households in Africa. Seeds are pulled onto a string of natural fibres and burned. Experimental cooking stoves for burning unprocessed seeds have been developed and will be covered in the chapter on Jatropha-based products.

Apart from these minor exceptions. the first step in Jatropha processing is extraction of the oil. The press cake has some value and several uses but the oil is the most valuable part. It is therefore paramount that as much oil as possible is extracted from the seeds in the most economical way. The oil content in the dry seeds varies between 31 and 38% depending on the seeds' provenance and growing conditions. The oil is the basis for all high-value Jatropha products. Due to its importance it is treated in some detail on the following pages. Oil purification is an integral part of the extraction process so it is covered here too.

First is a brief discussion on the implication of oil extraction technology on the Jatropha Value Chain. Next we explain why powered screw presses serving a community provide the best balance between efficiency and local development. The current state of knowledge about powered screw presses for Jatropha oil extraction is assessed to find out what advances can be expected in the near future.

Efficient Oil Extraction

Oil Press Technology Choices Impact the Jatropha Value Chain

Technology choice for oil extraction has significant impact on how Jatropha cultivation can be organised, on the products that can be produced, and on the local development effects that can be achieved.

In practice three levels of Jatropha value chains can be distinguished, each based on a particular oil extraction technology. All three are currently operational at different locations and can therefore be assumed to be viable at least under some circumstances:

Household Level One or a few families cultivate Jatropha and process their own seeds with a hand press. The oil is used mainly to produce soap and sometimes for lamp oil. The quality is insufficient for engine fuel. Very hard labour is required to operate the press and the efficiency is low. Because cultivation and processing take place at the same place it is easy to close the nutrient loops to create sustainable cultivation systems. The low return on labour means that only in areas with very low income levels will the hand press be of interest. However, in such areas farmers do not have the resources to invest in a press. This is supported by experience from Zimbabwe and Tanzania. As presently practiced in Zimbabwe, the investment is around $300 US/farmer (hand press only plus drum for sedimentation). In Tanzania it was found that most households are not in a position to make such an investment. For this reason local energy production with Jatropha will only work if processing can be organised and carried out at community level (Ehrensperger, Portner, and Kiteme 2012).

Community Level Farmers are organized in farmers groups, trained by extension workers from NGOs or government, delivering seeds to a central workshop/factory that produces PPO or biodiesel of sufficient quality for use in cars and diesel engines. This is a widely-used approach and all the Hivos-supported projects employed it.

			
Hand press: Bielenberg type	**Small powered press: Double-Elephant**	**Large powered press: KEK P0500**	**at MBSA, Mali: Butane SOXHLET**
Family or village groups	Small processing workshop	Medium industrialised processing workshop	Larger industrialised workshop
6 kg seeds/hr	100 kg seeds/hr	500 kg seeds/hr	3000 kg seeds/hr
Press Investment: ca €200	ca €2,000	ca €65,000	ca €500,000
Main product: Crude oil for soap	Crude oil for soap	PPO + biogas +soap	Biodiesel + various products

Table 1: Oil presses (data and photos: Jan de Jongh, FACT Jatropha Handbook, Peter Beerens and Hugo Verkuyl)

Diesel- or electric-driven mechanical strainer presses are used with oil purification by plate filters and/or candle filters. Laboratory equipment and capable staff should be present to check the quality on a regular basis. This has not been the case everywhere but experience shows that quality control is crucial.

The central workshop usually delivers a range of other products, whenever a local market is available. The smallholder farmers should preferably have a share in the central workshop and receive dividends from it, in addition to income from seeds. Typical investments in a central workshop are $20,000 – $50,000 US (not including building costs), for production by 500-5000 farmers. Per family the investment is just a tenth of that required for hand presses owned by individual farmers. Oil production (pressing plus cleaning) efficiency is around 18 %. (clean oil/seeds weight). (from Newsletter on Arrakis website from 5-10-2012, Hivos expert meeting).

Depending on the population density and the intensity of Jatropha production, transport distances are kept below 15 to 80km. This makes the return of the press cake or slurry to the farms manageable and keeps transport costs sufficiently low.

Regional Level By operating at the regional level it becomes feasible to use industrial scale equipment like solvent extraction to increase both quantity and quality of oil extracted. A current example is Mali Biocarburant (Verkuijl 2012). The equipment costs are above $100,000 US.

With regional processing it can be feasible to extract high-value components from the oil for special markets. The energy required per litre of oil produced is less with industrial scale equipment. A high skill level is required, but since the staff number is small compared to decentralised processing this is relatively easy to manage. In other words, from a processing perspective there are many advantages to centralised large-scale processing of Jatropha.

However, the long transport distances that inevitably result from centralised large-scale processing make it difficult to return the press cake to the farmers. Local production of soap, lamp oil and other products becomes less feasible for the same reasons. Processing skills are not developed locally and no local employment is created in Jatropha processing. Jatropha tends to become yet another cash crop that is exported out of the area where it is produced. The local development benefits that can be achieved with other modes of production are absent and it is therefore only of marginal interest in the context of this publication, namely Jatropha for local development[9].

Because powered oil expellers operating at the community level are the most promising option for Jatropha for local development, the current state of this technology is explored in details in the following section.
The less promising technologies, namely hand presses and solvent extraction, will only be covered briefly to provide the full picture. However, they should not be rejected. A mix of technologies may be the best option in some circumstances, e.g. a regional processing plant for biodiesel may co-exist with a community-owned press used for soap and lamp oil.
In Table 1 above, the required number of participating farmers increases from left to right, starting with a hand press operated by one family (e.g. Environment Africa, Zimbabwe) via small processing workshops with some 1000-2000 farmers (e.g. FACT/ADPP project Cabo Delgado), through medium industrialised workshops with several thousands of farmers (e.g. Omasi and Diligent in Tanzania) to a larger industrialised workshop producing biodiesel with a high-tech costly solvent extraction unit, working with more than 10,000 outgrower farmers (who

9 We want to stress that this is not a value statement. The more cash crops farmers have at their disposal the more resilient they are and the better they can match crop mixtures to their needs and resources. Regional processing can therefore be useful for farmers. However, this publication focuses on systems that create multiple local benefits beyond mere income.

have also shares in the processing company, and benefit from the profits made by the processing company, in addition to the sales of their seeds) (e.g. Mali Biocarburant).

Hand Presses

In Tanzania, Zimbabwe, Malawi and other countries there are several examples of household or village-based Jatropha oil production relying on hand presses mainly for making soap for own consumption and sale on local markets.

The presses used are of the Bielenberg type [see Jatropha handbook (Putten et al. 2010)] with a typical capacity of 1 litre/hour (1-man operation, very heavy labour). Typical efficiencies are 15% to18% crude oil extracted so 5 to 6 kgs of seed are required to produce one litre of oil. The crude oil still contains particles and fines (Prakash 2012; Jongschaap 2007). Hand-operated presses are generally not feasible for Jatropha PPO high-quality oil extraction.

A recent survey covering Malawi, Zambia and Zimbabwe found that hand presses are profitable in some poor areas even at yields as low as 300 kg/ha (Shumba et al. 2011), in particular if soap is produced locally (see Table 2). The costs of purchasing and maintaining the press are not included. If they were, even the farmers with the highest Jatropha yield would only just break even, assuming that each household has its own press. If a press is shared by ten or more households the cost does not significantly affect the profitability of oil extraction and the investment per family is similar to that for powered expellers.

Seed yield, tons/ha	0,3	0,8	1,3	1,8
Oil yield, kg	60	160	260	360
Bars of soap produced. 750g each	120	320	520	720
Press-cake, tons	0,24	0,64	1,04	1,44
Income from soap sales, $	90,00	240,00	390,00	540,00
Costs, $				
Pruning	9,74	9,74	9,74	9,74
Harvesting	16,20	43,20	70,20	97,20
Shelling,	10,80	28,80	46,80	64,80
Oil pressing	22,50	60,00	97,50	135,00
Caustic Soda	27,00	72,00	117,00	162,00
Soap making	3,60	9,60	15,60	21,60
Total variable costs	89,84	223,34	356,84	490,34
Gross Margin	0,16	16,66	33,16	49,66

Table 2: Gross margin for value addition to Jatropha seed: soap making in Mudzi district (Shumba et al. 2011, 18) For underlying assumptions see footnote[10].

Hand presses have a long history and have been optimised for longevity, easy maintenance and cheap manufacturing. It is therefore not expected that prices will drop significantly in the future.

Limited work has been done on optimising hand presses for Jatropha. Further work may improve efficiency by a few percentage points and reduce the clogging problems. However, this will not make hand presses significantly more attractive to farmers. Hand presses for Jatropha processing will likely remain non-viable except in rare circumstances.

Powered Oil Presses

Different types of powered oil expellers have been used for Jatropha processing and it has been found that strainer types of presses are better options than small cylindrical hole presses (FACT Jatropha Handbook: Putten et al. 2010).

Motor- or engine-driven presses should only be operated by trained operators. Otherwise oil quality, equipment maintenance and longevity will suffer. This imposes some constraints that are not found with the hand presses. The areas where Jatropha is most suitable usually lack skilled people and training on the job is therefore required. The experience has shown that it is difficult to keep press operators for long. Once they are trained they often migrate to less remote areas with more opportunities.

Typical presses used in pilot projects in Tanzania, Mozambique and Zimbabwe were Sayari presses with a maximum capacity of 70 kg seeds/hr (an Indian design copied in Tanzania), and Double Elephant type Chinese presses with capacities of up to 140 kg seeds/hr, costing a few thousand euros.

When more industrialised workshops started to develop (e.g. Diligent and Omasi (TZ), TNT (MW), MBSA (Mali)), larger and more expensive types of presses were introduced. These featured production capacity ranging from 140-500 kg seeds/hr from manufacturers such as Egon Keller (KEK), De Smet Rosedown, and Reinartz. The largest press costs € 64,000 (Beerens and de Jongh 2008).

Typical measured efficiencies are 15 – 25% crude oil and around 18% neat oil. (Ranges reported from 11 – 25% (Hamoen et al. 2011, Hugo Verkuijl pers. comm.).

10 Assumptions for gross margin calculations (Shumba et al. 2011, 17):
- *Planting material and its establishment cost: assumed to be zero as the live fences/hedges*

were already established.
- Pruning: 4.8 labour days are required to prune 1 ha of Jatropha plants at a plant density of 1,000 plants/ha.
- Harvesting (including picking the fruit): 27 labour days are required to harvest 1 ton of seed.
- Shelling (including thrashing and winnowing): 18 labour days are required to shell 1 ton of seed.
- Weeding: 7.2 labour days are needed to weed 1 ha of Jatropha.
- Seed oil content: The oil content of Jatropha seed is 33%. It was assumed that the available manual expressers can only extract the oil at 20%. 1 ton of seed will therefore produce 200 litres of oil.
- Soap-making step 1: Mix oil with Caustic Soda and water to produce a liquid soap mix. 1 litre of seed oil mixed with 150g of Caustic Soda and 750 ml of water will produce 2 bars of soap with a weight equivalent to 750g per bar.
- Soap-making step 2: Involves the moulding/shaping and drying of the soap mix. 6 labour days are required to produce soap from 200 litres of oil or 1 ton of seed (steps 1 & 2).

Hamoen et al. have performed some research on improving a De Smet Rosedown Mini 500 press, including improving processing speed and oil quality (Hamoen et al. 2011).

The cost of oil processing is also influenced by the longevity of the equipment and maintenance costs. There are still not sufficient results of long-term pressing with Jatropha to reliably assess these factors and it is therefore common to rely on experience with other oil crops. However, experience shows that in remote areas, low skill levels combined with difficult access to spare parts and tools can significantly reduce the longevity of oil expellers.

Despite the positive technological, economic and environmental features of using PPO instead of biodiesel, up to now there have been hardly any projects in which PPO is used as fuel in considerable amounts in daily operation (Elmar Dimpl 2011; own experience). This is mainly because almost all Jatropha projects have immature plants that have not yet reached full yield. This is also true of the Hivos-funded projects. The longevity of converted engines, durability and maintenance is therefore unknown.

Developing an oil-processing workshop for PPO oil of sufficient quality to use in diesel engines requires an industrial approach, which is difficult to achieve in rural areas. Achieving sufficient PPO quality is already a challenge in itself (de Jongh and Nielsen 2011). This cannot be achieved at household level and only with difficulty at the community level, since high competence is required of the operator. This requires investment in training and expert knowledge, purification equipment and quality control.

Soxhlet Extraction

The following step up in volume and complexity comes from a change from pressing technology to solvent extraction and esterification of crushed oil seeds into biodiesel. The costly equipment (in the order of $500,000 US for a 20 tons/day unit) requires a larger operation volume, diversification in oil feedstock instead of only Jatropha, and delivering a number of products. With this kind of equipment over 90% of the oil contents of the seeds can be extracted.

Experiments with separating components from the Jatropha oil for high-value products have started, but have already proven their value in the Castor industry for example, which is also a potential non-edible oil seed.

The minimum scale of operation for solvent extraction requires around 12,000 smallholders. MBSA in Mali has invested in such equipment and is planning to scale up with units in neighbouring countries such as Burkina Faso and Senegal (Verkuijl 2012).

Optimising the Powered Oil Presses for Jatropha

All oil extraction technologies used for Jatropha were originally developed for other crops. Adaptation and optimisation for Jatropha oil extractions has been undertaken by various research institutions and manufacturers over the last few years.

Peter Beerens studied oil extraction from Jatropha seeds in two low-capacity screw presses: a) the BT50 press in the Netherlands, and; b) the Sayari press in Tanzania. The test results showed close resemblance to additional Jatropha press tests conducted at two industrial German press producers (Beerens 2007).

To optimise oil production using screw presses, Beerens studied the effect of 5 *Independent variables:* Rotational speed, Restriction size, Hull content, Moisture content and Cooking. These variables change the *Dependent variables* of interest: Oil recovery, Temperature, Pressure, Throughput, Energy requirement and Oil point pressure. While a high oil recovery is the main aim of the process, other variables can affect the oil quality; e.g. a high temperature will increase the phosphor level in the oil which is bad for the engine due to its acidity.

The main findings of the study were:

- Moisture content has the strongest effect on oil recovery;
- Restriction size and rotational speed of the screw are other influential parameters;
- Oil recovery values for untreated seeds under standard circumstances were 79% and 87% for the BT50 and Sayari press respectively. After one hour cooking in water of 70°C, oil recovery increased to 89% and 91% respectively;
- The Sayari expeller requires dual passing of the material compared to single passing for the BT50.

Taking into consideration all the test results, Beerens concluded that for optimal oil recovery:

1. Moisture content = 2% to 4%;
2. Cooking at 70°C for one hour;
3. 100% hull content;
4. Smallest restriction size;
5. Lowest speed possible.

(Beerens 2007)

Another interesting study on optimising screw press parameters was carried out at Wageningen UR by Hamoen and his colleagues using the Mini100 strainer press of De Smet Rosedowns[11] (Hamoen et al. 2011). To maximise oil yield, the effect of the following two parameters on reducing the 'fines fraction' in the oil were studied:

- **Gap between hump and barrel** – The 'hump' is the screw element where the Jatropha seeds are highly compressed to release the oil. A thicker hump results in a narrower gap. The Mini100 has 3 types of humps, with 5, 3 and 1 mm gaps.

11 See http://www.desmetballestrarosedowns.com/minipresses.html

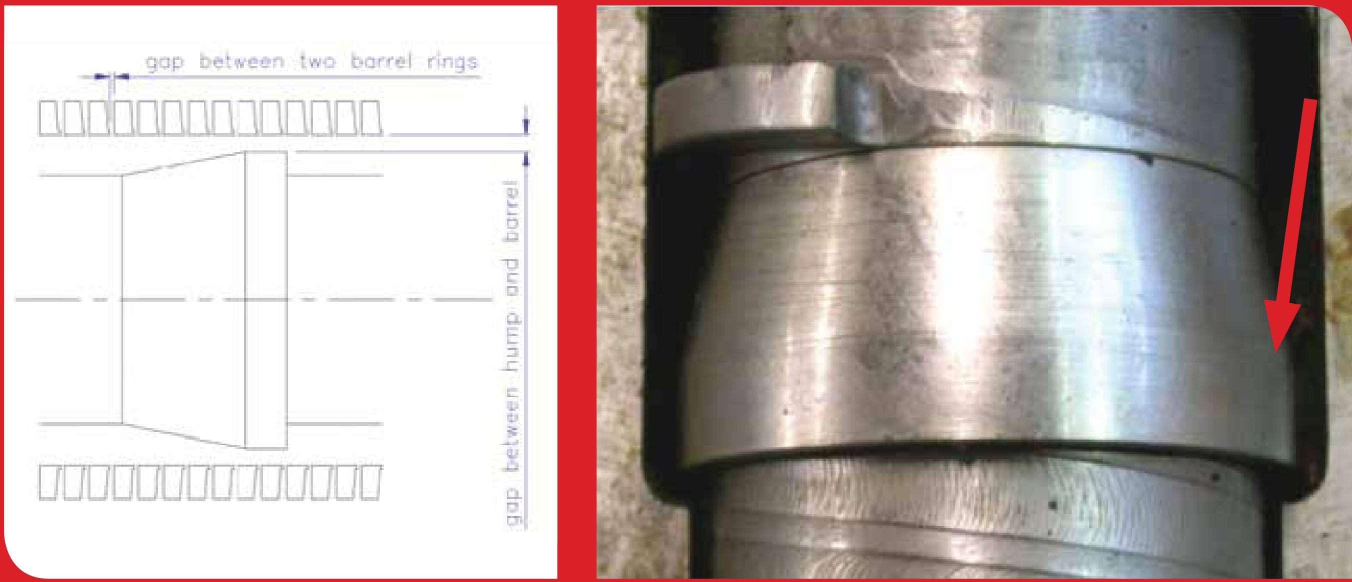


Figure 7: Gap between hump and barrel, and between barrel rings (Hamoen et al. 2011)

- **Gap between barrel rings** – The barrel consists of a large number of gaps, through which the oil can leave the screw press. These gaps are formed by adding small spacers between the barrel rings. The spacers have standard thicknesses of 0.048, 0.040, 0.028, 0.025, 0.020, 0.015, 0.010 and 0.005 inch.

The ‘cylinder hole press’ produces oil with a lower fines fraction because the oil leaves the press from an unpressurised zone even though the oil is expelled from the seeds in the high-pressure zone at the end of the screw. Hamoen et al. tried to apply this principle to find optimal values of the two gaps in a ‘strainer press’ that would give a minimum fines fraction in the oil. The length of the last hump was also varied since this was causing blockage of the press. The main conclusions were:

1. Optimal oil yields are obtained at relatively high speed press feeding. This requires high screw speeds to prevent press from getting overfilled.
2. A smaller gap at the final hump does not result in higher (clean) oil yields, due to the higher amount of fines in the oil;
3. Closing the gaps between the barrel rings at hump locations does not clearly affect the fine content in the oil, but is likely to have a positive effect on the energy factor. Closing too many of these gaps (towards the inlet) results in undesired ‘floating’ of the Jatropha seeds, which obstructs the transport of the seeds inside the press.
4. Suggested optimal configurations for Jatropha pressing in the Mini100 press are: a) using 0.38mm spacers (0.015 inch), and; b) closing the two gaps before the thickest part of the hump.
5. The large second hump should be replaced by a small one together with a dummy element to prevent blockage of the press.
6. Oil quality can be improved by removing free fatty acids by adding NaOH. Secondly, the production efficiency (and capacity) can be increased by removing the non-value-adding sub-processes (i.e. replacing the sedimentation vessel by a pressure leaf filtration) and by increasing the daily production hours and working in 3 or more shifts.
   (Hamoen et al. 2011)

Mobile Powered Presses

So far only stationary oil expellers have been used, which leads to additional costs for transport of seeds to the expeller and for transporting seed cake and oil back to the farmers.

There are several advantages in carrying out the oil expelling in a decentralised way closer to where the Jatropha plants are cultivated. Small mobile oil expellers can be taken to the Jatropha fields using an off-road pick-up truck with 4-wheel drive. It is logistically easier and cheaper to transport the seeds to the nearby expeller and to use the hulls and press cake as fertiliser. Press cake can be used to produce biogas locally that can fuel the oil expeller.
Each oil expeller will be operated at numerous sites on the farmers’ Jatropha plantations. Each site will have its own biogas storage and composting facilities. Another benefit of the mobile expeller is that only one operator is required.

However, there are practical issues that make mobile oil expellers fairly difficult to implement. The general complaint is that the equipment is not strong enough to withstand frequent transportation on rough roads, and the infrastructure of a fixed pressing point such as building for storage, bags, additional transport, power etc. is missing. Moreover, the logistics of producing biogas to fuel the expeller can rule out this option because the mobile expeller may visit an expelling point and use the biogas once every two weeks during picking time, whereas the unit may not be used for the next six months (during which there may be no seed cake or other biodegradable feedstock for the biogas digester). (Ab van Peer, 2013, pers. comm.)

Photo 6: Mobile Oil Expeller at Mali Biocarburant (Ab van Peer 2013)[12]

Expected Improvements in Oil Extraction

Powered oil expellers have been produced and optimised for a long time and no significant price reductions or major technical improvements are expected.

As explained above, detailed work has been undertaken on optimising powered oil expellers for Jatropha processing. The important parameters and trade-offs are well understood. The main obstacle to improved efficiency is now at the implementation level, i.e. sharing knowledge and training press operators. Larger seed size can increase the oil yield per kilogram of seeds simply because the hull fraction is smaller. In the chapter "Reducing Farmers' Production Costs" it is argued that the seed size is likely to increase over the coming years.

Some technical improvements may come from pre-treatment of Jatropha seeds, e.g. through boiling, microwave treatment or enzyme treatment. Some work has been undertaken but at this stage it is difficult to judge the potential, cost efficiency and suitability for application outside laboratories.

Overall it is likely that technical progress will increase the efficiency in Jatropha oil expelling by 2-5% over the coming five years. Much larger improvements are expected from the dissemination of existing knowledge and better training of press operators. In rural Africa in particular, presses have been operating very inefficiently, often extracting less than half of the amount possible and producing poor-quality oil. In other words the fastest way to improve oil extraction efficiency in the short term is through training and knowledge dissemination.

Product Diversification

The price that farmers can receive for Jatropha seeds depends on the products made, their value and the cost of processing.

The focus of most Jatropha value chains has so far been on fuel for combustion engines. With low fossil fuel prices, Jatropha is barely profitable if only the oil is used to substitute diesel. Fortunately a number of valuable products can be produced from the oil and the press cake.

In this chapter, products are divided into two broad categories, namely the ones derived from the oil and the ones derived from the press cake. As mentioned earlier there are a few niche applications for unprocessed seeds, namely traditional "seed candles" and Jatropha stoves burning full seeds. The candles are a curiosity whereas the Jatropha seed stove has some potential. It is covered together with oil-based stoves.

12 Ab van Peer, 2013, Review of Draft Report

Some products are drop-in replacements (e.g. soap and biodiesel[13]) and therefore uncomplicated to introduce: the products are known and accepted, and distribution channels are in place.

However, some important Jatropha-based products are not drop-in replacements but require adaptations (e.g. engines for PPO) or special equipment (e.g. lamps and stoves). To establish a local value chain that includes these products is much more demanding.

Products Based on Jatropha Oil

Liquid Fuel for Combustion Engines

There are two main pathways for using Jatropha oil to power combustion engines: it can be used directly in slightly modified diesel engines or converted into biodiesel that can substitute fossil diesel. Both approaches have been tested extensively in the field.

	Positive	Negative
PPO	Low fuel production cost	Cost + expertise needed for modification of engine
Biodiesel	No modification of engine needed	High fuel production cost + inputs methanol + caustic soda + expertise needed.

Table 3: Comparison of PPO and Biodiesel

In areas where Jatropha for local development has the highest potential, the number of combustion engines is usually limited. Apart from a small number of vehicles there are often stationary engines powering water pumps, generator sets, maize mills and other agricultural machinery. Simple stationary engines are the easiest and cheapest to adapt for PPO use. This makes a strong case for avoiding the complexity of producing biodiesel and only using PPO.

However, currently the expertise needed for modification of the engines must be brought in from outside at a significant cost. This is mainly an issue of training and skill transfer to local professionals. The parts used for modifying one engine cost from $20-$50 US.
That price could be cut at least in half if standard conversion kits were available. However, due to the diversity of engine types found in rural areas and the limited demand for engine adaptations at this time it is not feasible to create standard kits.

The advantage of biodiesel over PPO is that diesel engines need no modification if a blend of biodiesel and fossil is used. If pure biodiesel is used, pure rubber fuel hoses need to be replaced with synthetic ones. Rubber hoses are mostly found on older models. Since poor countries generally have a high proportion of older cars, more vehicles will be affected.

None of the smaller projects or companies have reported that biodiesel from Jatropha is being produced economically, i.e., in all cases the production price was higher than the market price. Projects that compared PPO to biodiesel found that PPO production was economically much more interesting.

One exception is MBSA in Mali which has increased to an industrial production level and invested in a butane soxhlet extraction and biodiesel production unit, enabling oil extraction to more than 90%. MBSA is working in cooperation with over 12,000 small-scale outgrower farmers and is expanding to neighbouring countries, including Senegal and Burkina Faso. Their target plan is to reach 6 million live Jatropha plants in 2015. They had reached break-even by 2012 (Hugo Verkuijl pers. comm.)

One area that looks promising but has so far not received much attention is running diesel engines on a mix of PPO and biogas. Since biogas can easily be produced from the press cake, mixed fuel engines have the potential to double the engine power or electricity produced from Jatropha seeds.

Main lessons learned

The often-repeated statement in general literature that stationary diesel engines, like Lister types, can run on PPO without modification of the engines has in practice proved to be false (de Jongh and Nielsen 2011). The cheapest modification measures consists of: a two-tank system, lowering the viscosity by using a proper heat exchanger, supplying an extra PPO filter, having fuel lines diameter increased, the injector time advanced, valve opening pressure increased and the engine temperature controlled with a thermostat. If the required maintenance is performed, engines with these modifications will perform well for a long time.

It is possible to modify diesel engines to allow them to 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. (For an extensive treatment see the FACT Jatropha Handbook: Putten et al. 2010)

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 very low temperature. This causes incomplete combustion of the PPO and increases fuel consumption and wear, thereby directly damaging the engine using PPO.

Running on good quality PPO with a suitable and well-converted diesel engine requires no extra maintenance. The need for ordinary maintenance like regular changing of lube oil and fuel filters might increase depending on the engine and usage.

Reasonably low-cost kits (around $200 US) can be imported from Europe, but developing a universally applicable modification kit that can be locally made is practically untenable.

If the market for PPO-powered engines expands sufficiently, factory-modified engines will eventually become available. Some of the existing engine designs for PPO engines like the Elsbett[14] engine may eventually enter mass production. However, this is unlikely to happen within the next five years.

13 This is true if biodiesel is blended with fossil diesel in low concentrations. A complete substitution may be more involved depending on the equipment used for fuel delivery and the vehicles consuming the biodiesel.

14 See http://www.elsbett-museum.de/funktionsweise/funktion.html

Stationary diesel engines with indirect injection (ID) can be converted to run on pure plant oil (PPO) for a low price. Standardized conversion kits are not feasible in practice because many different models of engines are in use. Of the low-cost engines, mostly imported from China or India, the Lister types of diesel engines are more suitable to run on PPO than other low-cost engines.

Improve Biodiesel processing

The optimisation of biodiesel production depends on numerous parameters such as renewable biological triglyceride sources, type of catalyst and alcohol for the transesterification reaction, molar ratio of oil–alcohol, and heating sources.

Several innovative experiments for improving biodiesel processing have been tried at laboratory scale:

1. Bojan and Durairaj (2012) investigated improved biodiesel production process with high free fatty acid Jatropha oil as input material. In one-step conventional base catalysed transesterification, the presence of high free fatty acid concentration (8.67%) reduced the biodiesel yield significantly (80.5%). Therefore a two-step acid pre-treatment esterification and base catalysed transesterification process was selected to improve the yield. During the first step the free fatty acid concentration of Jatropha oil was reduced to 1.12% and in the second step, alkali based transesterification gave 93% yield.
2. Lab experiments showed that it is possible to develop biodiesel production as a continuous process instead of the usual batch production by using enzymes in the transesterification, which is also more eco-friendly than the chemical process. Anapurna Kumari et al. report the use of a combination of immobilised lipases (enzyme) with t-butanol as a solvent to efficiently produce biodiesel from Jatropha oil (Kumari et al. 2009).
3. Microwaves and ultrasound have been used in some lab experiments to reduce energy requirements and speed up the conversion process (Koberg and Gedanken 2012).

From the rapid pace of research publications exploring new ways of improving biodiesel production, it is clear that there are still many options left to explore. Many small improvements have been shown to work on a small scale in laboratories. However, in many cases it is unclear whether they can be scaled up to production level and whether or not it will be economically feasible to do so. Many technologies target industrial production.

Some of the technologies like microwave and ultrasound heaters, enzymes and exotic chemicals are unlikely to become available in the rural settings where Jatropha for local development has its largest potential.

It is to be expected that some of these experiments will be developed into real applications over the coming five years. However, most of these improvements will be applied in centrally-located facilities rather than small units in rural areas, in view of the high level of technology required, the availability of required materials and spare parts, and the cost.

Probably they will be restricted to large-scale industry, which brings economy of scale when higher investment levels of advanced technologies are introduced.

One exception will probably be the further expanding of rural processing units using the butane solvents extraction (as planned for implementation by MBSA in 2013). Probably over the next 5 to 10 years other companies will follow with a similar approach.

Oil Purification and Oil Quality

For uses like soap production, sedimentation gives sufficient oil quality. However, for PPO as fuel in engines the quality should fulfil the requirements for biofuel as laid out in standards like the European EN 14214 or the American-Canadian ASTM D6751 standard.

- Sedimentation and filtering with cloth and candle filters (under pressure) is sufficient treatment of the Jatropha oil when used directly in combustion engines.
- Jatropha oil of sufficient quality for direct use in engines is only obtainable if harvesting, seed handling and operation of the presses is carefully managed.
- It was found that the colour & transparency of the oil indicates the acidity level and can therefore be used in day-to-day operations for optimising the oil quality.
- Low-quality Jatropha oil can be processed efficiently by simple neutralisation with caustic soda, but it is doubtful if it is economically viable, due to the extra expense and the loss of oil in the process.
- 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 for obtaining an indication of the oil quality.
- However, the oil quality can only be determined exactly by using an accredited test laboratory to execute the required testing of the PPO on the standards as set in EN 14214 or ASTM D6751.

Purification of the expelled Jatropha oil is rather wasteful and only limited experimentation has been undertaken. Improvements in both neat oil yield and cost efficiency should be relatively easy to achieve by experimenting with already-available techniques for sedimentation and filtering.

Figure 8: Jatropha oil lamps. From left to right: a) Binga lamp, b) lamp burning sunflower oil, and c) simple, efficient, low-cost, plastic floating wick made by GTZ in Tanzania (photos: GTZ, Jan de Jongh)

Oil for Stoves and Lamps

Over the last few years, several attempts have been made to develop stoves and lamps that can use Jatropha oil or other vegetable oils, but there have been no reports of large-scale manufacture of any model of stove or lamp. An overview of various stove types are given in the FACT Jatropha Handbook (Putten et al. 2010). There are some reports that Jatropha oil stoves do not yet work properly (Eijck et al. 2010).

Lamps

The lamp that does work is still the very simple ‘Binga lamp’. As the oil level drops the floating wick sinks together with the oil, keeping the distance between the flame and the oil constant. An impression of the Binga lamp is given in Figure 8.

The underlying physical problem is the high viscosity of the oil, which hinders a good flow to the wick, and the low temperature of the flame at 100-200˚C. This temperature is sufficient for normal paraffin lamps but for the fatty acids in the Jatropha oil to burn properly a temperature in the range of 220-300˚C is required (Oomen 2008). Users in Tanzania have reported that this causes coking of the wick after a while, which requires frequent cleaning.

Some institutes claim to have solved this problem. For example, Kakute in Tanzania has introduced a copper tube to heat up the oil. However, evidence of the success of this technique is difficult to find.

Better burning of the wicks can be influenced by the wick type, by the composition of the oil, and especially by the fatty acid composition (Oomen 2008). Oomen suggests performing additional experiments to determine the effect of the separate fatty acids. These experiments should indicate the range of fatty acids which negatively impact the burning characteristics. Secondly, a method to remove or avoid the fatty acids must be found. This could be a separation method or by finding a sub-species of Jatropha with an intrinsically smaller amount of these fatty acids. If the research by Oomen can be continued, it could be expected that within 5 years a better-burning wick will become available. Such a wick would be usable for lamps and stoves that burn Jatropha or other vegetable oils.

Furthermore, some research has been done on the exhaust fumes. For example Hamoen et al. (2011) concludes: “PPO produces less PAC (240 times less), CO_2 (3 times less) and soot (1.5 times less) than standard paraffin. However the production of NOx (5 times), CO (2 times) and CxHy (7 times) are higher than standard paraffin. Especially the use of the special wick leads to good results; with the special wick overall values are below the European Mac values”.

Stoves

Stoves can use either Jatropha seeds or Jatropha oil as fuel. Three stoves that use complete or crushed Jatropha seeds as fuel are the *“UB – 16 Jatropha curcas L seeds stove”*, the *“Jiko Safi stove”* and the *“Jiko Mbono seeds stove”*.

UB – 16 seeds stove | Jiko Mbono stove | Jiko Safi stove

Figuur 9: Jatropha seed stoves (photos: E. Widarayanto, Erin Rasmussen, www.jetcitystoveworks.com/)

The UB-16 stove is fired with Jatropha seeds, with the seed hull removed for better burning as the energy content per unit mass is higher for the seed kernel. In 2008 and 2009 more than 11,000 units were distributed in Indonesia (Widaryanto 2010).

The Jiko Mbono stove was developed by Kiwia & Laustsen Ltd with support from "Partners for Development" in Tanzania for burning whole Jatropha seeds. This stove is a TLUD (Top-Lit UpDraft) gasification stove with natural draft air supply. Initial testing found that pellets from Jatropha press cake are a better fuel for the stove because they have a much lower oil content, and this led to the Jiko Bomba stove that can use pellets made from Jatropha cake, rice husk and other agricultural wastes.

The stove is made entirely of sheet metal and can easily be fabricated in a small workshop. Manufacture of the Jiko Mbono stove is described at http://wn.com/cooking_stove_operating_on_jatropha#/videos.

The Jiko Safi stove, also a gasification stove, was developed by the non-profit Jet City StoveWorks of Seattle, USA and tested in Tanzania. It gives a steady hot flame for 90 minutes on one load of seed (0.7 kgs). (www.jetcitystoveworks.com)

One stove that can burn Jatropha oil is the PROTOS Plant Oil Cooker developed by BSH Bosch und Siemens Hausgeräte GmbH who conducted field trials in various countries (Bosch & Siemens 2010). The PROTOS is a high quality stove that is safe, easy to use and cheap enough for people in developing countries, but regular cleaning is necessary because plant oil leaves residue in the burner due to its chemical composition. Due to the extremely high flash point of plant oils, Bosch and Siemens had to design a technically sophisticated device that can operate at much higher temperatures and has a longer pre-heating process than conventional stoves burning a fossil fuel like kerosene. Series production began in Indonesia in the middle of last year, but BSH and its partners have now decided to discontinue further production and close down the Protos plant oil cooker project. This is because it has not met with the success originally envisaged, due to complex technical and operational factors. These include difficulties in setting up a supply chain for sustainable cultivated plant oil and the low purchasing power of the potential users. Nevertheless, construction plans and technical documents for manufacturing the PROTOS stove are available for download to any interested party at http://www.bsh-group.com/index.php?page=109906.

The question of whether certain types of lamps and stoves are going to be used on a large scale depends on many factors and circumstances. Even in sub-Saharan countries, solar lamps and LED lamps powered by batteries (Nielsen 2009a) are entering the market and may become the most prevalent type of lamp in the coming 5 years.

The personal choice of a certain stove for example depends on interrelated issues such as those found in the study of Takama et al. (2011): the factors playing a role in the socio-economic attributes are income, opportunity costs, gender, education and household size, while in the product-specific attributes the factors of fuel cost, stove price, maintenance cost, safety, risk and aesthetics play a role. Takama found for example that lower-income households, which are prevalent in rural areas, are more concerned about the initial cost of the stove than about the fuel cost. It was also found that as compared to the low-income group, the high-income group was willing to pay ten times as much for a unit reducing indoor smoke, two times more for increased efficiency, and ten times more for increased safety, in some cases.

It is therefore very hard to predict whether any of the stoves under development are going to be used on a large scale within the coming 5 years.

Soap

Several projects have experimented with local soap production and found it more profitable than fuel production. This has the added benefit of reducing the quality requirements for the oil and thereby the processing costs, as well as involving more people in the processing. Jatropha soap has also been made in small quantities directly from crushed seeds without extracting the oil.

Basic soap production is simple and apart from temporary unavailability of caustic soda it has proved both viable and manageable under even the most difficult circumstances. At most locations, it has fetched a higher price than the cheapest industrial soap in the market due to its white colour and sometimes due to its perceived medical properties stemming from the poisonous substances in the oil.

This has however also led to concerns over the safety of Jatropha soap. Fortunately recent tests of Jatropha soap in Germany found that it fulfils government regulations there for cosmetic soap (Tatjana Vollner 2011). More comprehensive tests are required, in particular to verify the medicinal properties to cure skin diseases before Jatropha soap can be marketed as a therapeutic product that will fetch a higher price in some markets.

In the Gota Verde project in Honduras, "liquid amber" from an indigenous tree is added to provide an attractive aroma. Such locally available natural aromas or small quantities of imported aromatic oils can be mixed with the soap products to make them more attractive and justify a higher price comparable with luxury soaps.

Quality soap requires good quality soft water. In areas with hard water, distilled water is commonly used for soap-making. This can be expensive in rural areas, and rain water is a good substitute. Rainwater harvesting equipment can be incorporated into existing buildings and the water stored for usage during the dry season.

Wooden moulds are common but moulds made of plastic of the desired shape have been found to be excellent for small-scale

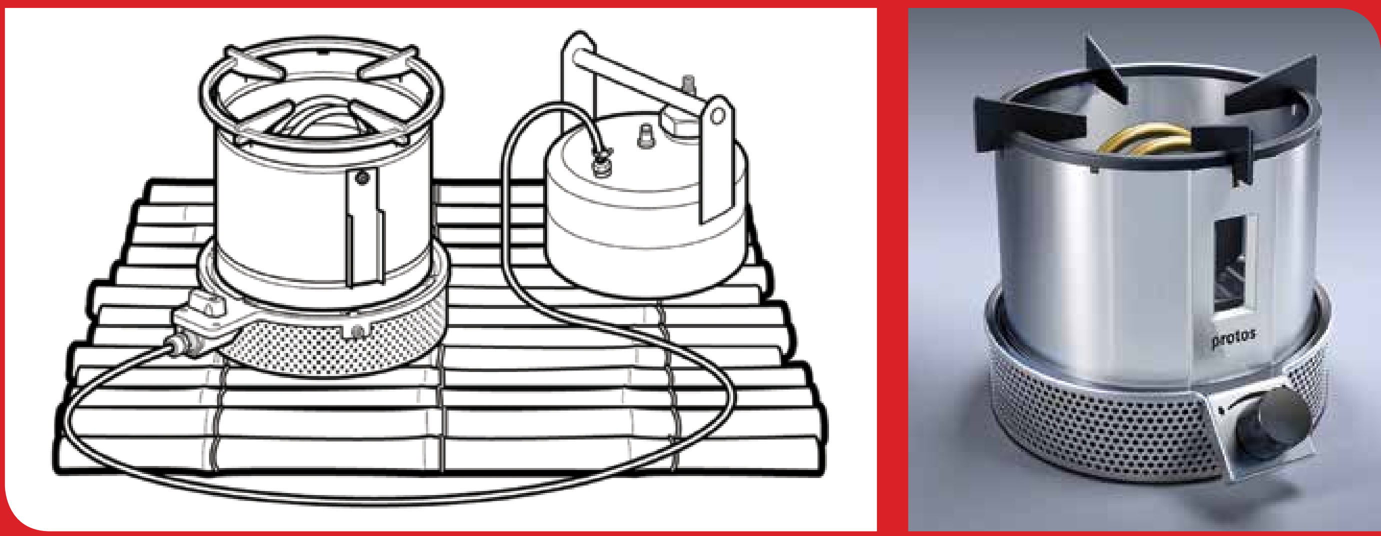


Figure 10: PROTOS plant oil cooker (Bosch & Siemens 2010)

soap-making, since it is easy to remove the soap after it sets and the soap can then be cut to pieces of the desired size.[15]

For several years, the company Best Natural Products at Arusha in Tanzania has been using Jatropha PPO to produce a range of soap and related products that include Washing Soap, Toilet Soap, Hand Wash, Shampoo, Shower Gel, Liquid Detergent, Disinfectant, Mosquito Repellent and Bio-pesticide. They have a Quality Control Laboratory where the composition of each batch of Jatropha oil is tested, chemicals are weighed accurately and the quality of the products is assured.

If the Jatropha oil is used to make biodiesel, then every 100 litres of biodiesel produced will give around 20 litres of the by-product glycerine which, after removing the methanol, can be used to make soap by mixing with water and lye (sodium or potassium hydroxide)[16]. Soaps with 15% to 20% pure glycerine are translucent and have a gentle, moisturising effect that is good for soft skins. On the other hand, an excess of lye produces soaps that have good degreasing properties – such liquid soaps can be used as a hand cleaner, and as a detergent for cleaning dirty, greasy floors, etc.[17, 18]

Since soap production is one of the most lucrative products from Jatropha oil and a rather simple technology that is feasible at household or community scales, it is expected that the number of soap producers will increase over the next 5 years. The profitability of soap production in most countries can be increased if manufacturers are provided with the technical expertise to increase their product range and assistance with marketing including attractive packaging. Some R&D is necessary to establish the efficacy of Jatropha soaps and allied products such as disinfectant, mosquito repellent and bio-pesticide; the results can then be used to support marketing efforts.

Bio-Pesticides

Bio-pesticide is another profitable product from Jatropha that is already being used in coastal Peru to effectively control four locally-occurring plagues. The CEDISA project is also selling Jatropha PPO as bio-pesticide to a GIZ project in Chiclayo at the elevated price of 18 soles (~$7 US) per gallon; i.e. the production cost of PPO is 10.8 to 14.4 soles per gallon, and the local mineral diesel price is 12.5 soles per gallon) (Prakash 2012). Research has shown that Jatropha pesticide is efficient against a wide range of pests (Devappa, Makkar, and Becker 2010). However the effect on beneficial insects, including pollinators, is not known.

15 http://www.youtube.com/watch?v=X9SAe2jSwv8. Accessed on 6 April 2013
16 1 liter (1000 ml) of glycerin with 200 to 250 ml of water and either 50 g of Sodium Hydroxide or 70 g of Potassium Hydroxide.

17 http://www.home-made-biodiesel.com/biodiesel-soap.html. Accessed on 6 April 2013.
18 http://www.permaculture.com/node/535. Accessed on 6 April 2013

Photo 7: Jatropha soap curing in wooden mould

Entomologists at the Crop Protection Department of the Cotton Research and Development Institute – CRDI in the Philippines have formulated an emulsifiable concentrate by a process of soaking powdered Jatropha seeds in petroleum ether, decanting and evaporation. The concentrate is diluted with water to form a uniform suspension that does not clog the nozzle of knapsack sprayers. Dust formulations can also be used. The bio-pesticide can be used to control a range of pests, both agricultural (bollworm, weevil, golden snail) and household (cockroaches, rats, houseflies). Since bio-pesticide from Jatropha is low cost, biodegradable and effective, it has the potential to capture part of the large market for conventional pesticides (Morales 1995).

Fine Chemicals

To increase the total value from Jatropha, several valuable chemicals can be extracted from the press cake and the leaves. This is done in a *Biorefinery* which is an integrated biomass processing facility that produces various added-value products. Jatropha press cake contains about 23-28% protein (essential amino acids) that can contribute as nutritional components for feed, while glutamine and glutamic acid (15 % of total nitrogen) can be used as intermediate to produce functionalised N-containing chemicals. Jatropha leaves are also a potential source of amino acids, but extraction and utilisation of leaf proteins might not be economically feasible due to the low recovery and low purity of current processes (Lestari 2012). Potential applications for protein from Jatropha are:

- Animal Feed (after detoxification);
- Technical uses – Emulsifier, Foaming agent, Coating / Bioplastic, Adhesives.

The potential value of using press cake as animal feed in Tanzania has been estimated to be $400 US/ton press cake compared to $160 US/ton as briquettes and $50-60 US as bio-char (Marieke Bruins 2012). Before the press cake can be used for animal feed, it has to be detoxified to remove the toxic phorbol esters, and this can be done in a 2-stage process using ethanol and then petroleum ether (Lestari 2012). Most probably this process will not be viable because of the cost of

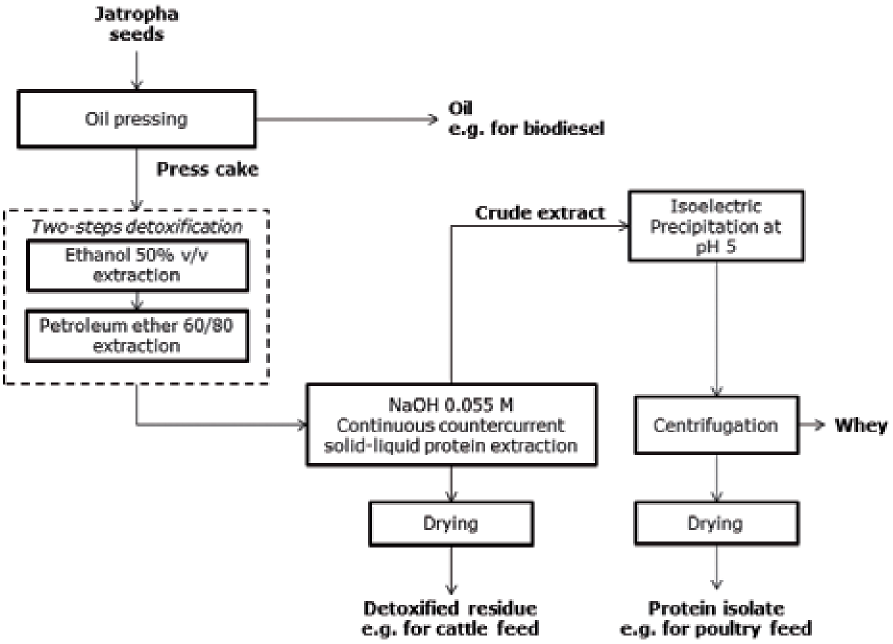


Figure 11: Process flow diagram for protein extractions from detoxified press cake. (Lestari 2012)

	Jatropha seed components	Potential rural products	Potential industrial products
1	Oil	Biodiesel	Biodiesel
2	Protein	Poultry feed	Coating / Paint, or Adhesives
3	Carbohydrates	Cattle feed	Ethanol
4	Fibre / Lignin	Briquettes	Binders
5	Ash / Minerals	Fertiliser	Fertiliser
	TOTAL VALUE of products @ 2000 kg seed /ha /year • Zimbabwe • Tanzania • Mali • Indonesia	 Euro/ha 542 622 634 703	 Euro/ha 5,601 6,541 13,100 7,101

Table 4: Rural and Industrial products from Jatropha seeds and their value

detoxification. Treating Jatropha for feed use is more complicated than with soy, and will probably not be feasible on a small scale. In the medium and long term, it is not likely that Jatropha press cake will be able to compete with non-toxic oil seed press cakes or to generate interest from the animal feed industry (Nielsen, Raghavan, and de Jongh 2012).

Jatropha seed products are produced using the two biorefinery steps:

- *Fractionation* into different components e.g. oil, proteins, carbohydrates, fibre/lignin, and ash/minerals.
- *Conversion* of the components into various products:
  a) *Rural products* using minor processing, or
  b) *Industrial products* using more advanced processing.

Whereas the total value of Rural Products from one hectare can provide income only for one person, the additional value of industrial products from the bio-refinery has the potential to generate enough income per hectare for 13 persons in Zimbabwe, 22 in Tanzania, 35 in Mali and 18 persons in Indonesia (Lestari 2012).

Nevertheless, it should be noted that:

1. The potential value of fine chemicals from Jatropha is based only on lab tests so far, and we are not aware of any work on the commercial extraction of fine chemicals. Moreover, the costs of commercial extraction are not known.
2. So far, no "killer chemical" has been found, i.e. a chemical that can be produced much more easily and cheaply from Jatropha than from other feed stocks.
3. Since the supply of Jatropha seeds is currently low and erratic, no serious investment in the development of fine chemicals from Jatropha is anticipated in the near future.
4. Therefore our assessment is that fine chemicals will not have any impact on the ground over the coming five years.

Products Based on Jatropha Press Cake

Biogas

The press cake can be used for biogas production in simple anaerobic digesters. The basic technique is well known and widespread. At several locations, biogas is now being produced from Jatropha press cake on an experimental scale.

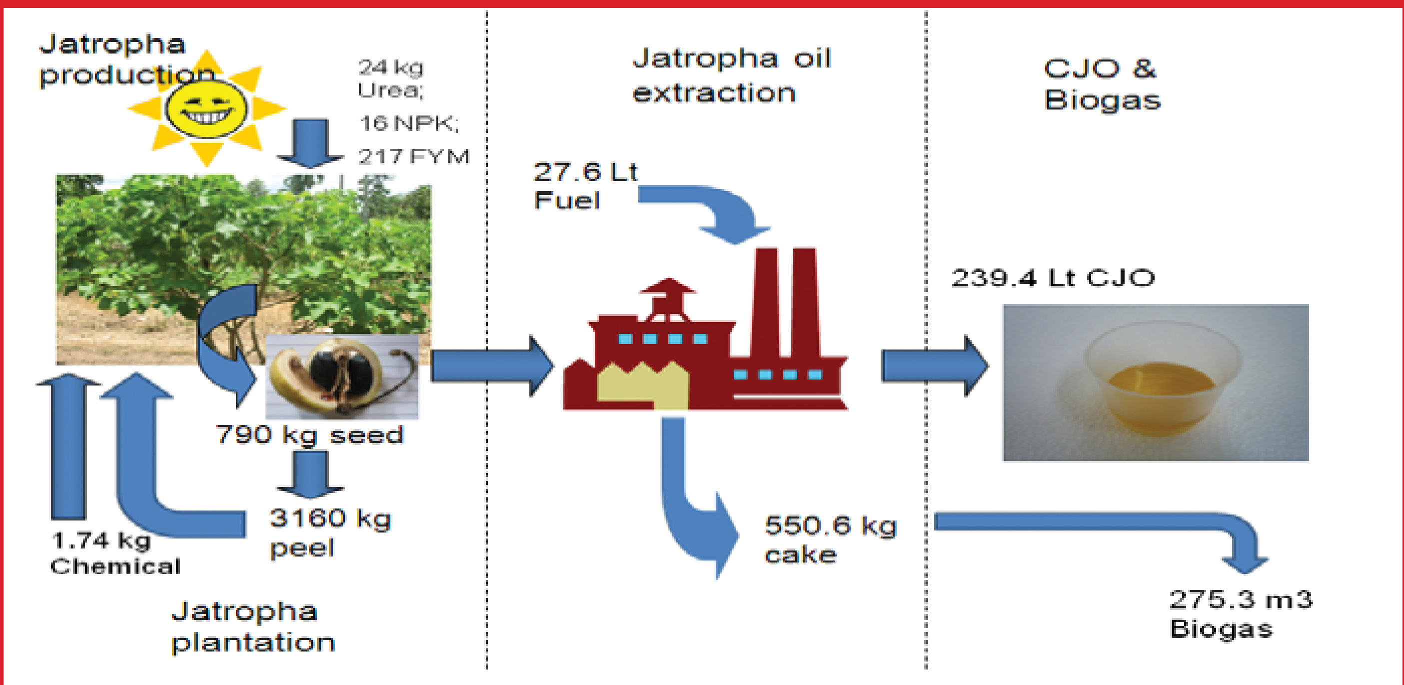
Biogas digesters are a very good way to extract the energy in the press cake as methane gas, and also return the slurry with most of the nutrients back to the plants. Seed cake and parts of J. curcas fruits can be used as feedstock for biogas production through anaerobic digestion. Biogas is generally considered to be a mix of methane and carbon dioxide (60:40) with a caloric value of about 20 MJ kg–1. The slurry, the by-product of seed cake fermentation, can be used as fertiliser. It has a high nutrient volume and, in addition, all pathogens are killed during fermentation (Contran et al. 2013). However, the composition can vary: methane (50%-75%), carbon dioxide (25%-45%), water vapour (2%-8%) and traces of oxygen, hydrogen, nitrogen, ammonia and hydrogen sulphide. The average calorific value of biogas can also vary from 21 to23.5 MJ/m³, so that 1 m³ of biogas is equivalent to 0.5-0.6 l diesel fuel or about 6 kWh of electricity (Elmar Dimpl 2011).

Between 0.4 m³ kg–1 and 0.6 m³ kg–1 of biogas could be obtained from the Jatropha seed cake, depending on the inoculums (e.g. pig manure, microbial consortia) and on the type of cake (e.g. dry seed cake, solvent extracted kernel, or mechanically de-oiled cake) (W.M.J. Achten et al. 2008). A small digester operated by MBSA in Mali that ran mostly on dung and press cake (1:1 in weight) produced around 0.35 m³ kg–1 cake (value was compensated for dung) but it was noticed that the slurry was not fully digested on exiting the system. The biogas composition was 58% methane, 38% carbon dioxide and less than 15 ppm hydrogen sulphide (Bart Frederiks, FACT Foundation pers. comm. 2013).

Biogas can be used for cooking / heating or for burning in engines to drive pumps or machinery or to generate electricity. However, it has to be used nearby, since transporting it requires removing the carbon dioxide and compressing the biogas, which are not feasible options for small-scale digesters. Biogas digesters using

In Indonesia, a private company foundation as a manifestation of corporate social responsibility developed the concept of Desa Mandiri Energi or Self-Sufficient Energy Village (SSEV) based on Jatropha at the village of Way Isem in 2007. There is no grid electricity at Way Isem and cooking and lighting were done with wood (gathered free) and kerosene. To start with, the foundation provided 100 kilograms of Jatropha seeds for the whole community of around 1,500 people, whose main occupation is farming.

Seeds from 40 ha of Jatropha plantations are supplied to an oil expeller run by a co-operative and the oil is used to generate electricity. The foundation later provided 20 anaerobic digesters of 1,200 L capacity so that the villagers could produce biogas from Jatropha press cake and use it to replace firewood for cooking. 2 kg of Jatropha press cake mixed with 18 L of water was fed into the digester daily to produce one cubic metre of biogas, equivalent to 0.6 L kerosene or 3.5 kg of wood. Other biomass waste from peeling and pruning is returned to the fields as compost (Konishi et al. 2010; ERIA 2010).



Jatropha press cake have operated successfully in Mali, Tanzania, Mozambique and other countries.

The Jatropha press cake has to be diluted with 4 to 5 times water by volume to maintain a proper flow in the digester. Such large quantities of water may not be available at many locations, especially during the dry season. Another important parameter for optimum biogas production is the carbon:nitrogen ratio, but this has been found to be within workable levels and does not require the addition of urine or urea (Bart Frederiks, FACT Foundation pers. comm. 2013).

The biogas digester is started (or sometimes restarted) by seeding with methane-producing bacteria which is found in cow dung, the excreta of pigs or human beings, or sewage waste (REF). The other biodegradable waste feedstock (Jatropha cake, kitchen wastes, rotten fruits and vegetables, etc.) are then introduced into the digester, increasing over a period of 15 days to the stable maximum level. Most biogas plants using Jatropha cake have operated in combination with either animal wastes (Mali – 1:1 with cow dung) or with human toilet wastes (Diligent in Tanzania) since this gives a more stable system and prevents micronutrient deficiency. In Mali a biogas plant was run on only Jatropha press cake for about six months but the long-term effects are not clear since Jatropha cake does not contain methane-producing bacteria (Frederiks, FACT Foundation pers. comm. 2013).

In addition to the traditional biogas digester designs used for several decades in China, India, etc. (made from bricks, cement, and steel), several low-cost, light-weight digester designs are now available for small-scale biogas plants. Two designs that have proven their reliability in tropical climates are: a) plastic bag digesters, and b) compact biogas plants. Both of these digesters are easy to transport to remote areas and can be installed quickly, and they can both be scaled up to larger sizes by using bigger plastic bags or bigger plastic gas holders.

Plastic bag digesters are another low-cost design that has performed well. This digester is a plug-flow type with feed added into one end of the long bag flowing through the bag and then taken out of the other end. The bag made of strong plastic is semi-buried in a pit, as shown in the photo.

The Compact Biogas Plant (CBP) was developed by ARTI in the state of Maharashtra in India for utilizing household kitchen waste to produce cooking gas. Tens of thousands of CBPs have been installed successfully in India and Africa. The CBP is a low-cost digester easily constructed from two plastic water tanks that telescope into each other – the lower tank (digester) is open at the top and the upper tank (gas holder) is open at the bottom and telescopes into the digester. The gas holder moves up and down inside the digester with production and usage of gas (http://arti-africa.org/compact-biogas-systems/). The CBP can easily be constructed locally within a few hours using two plastic water tanks and a few pieces of pipe. See http://www.youtube.com/watch?v=xoJTlhfjpXQ . ARTI has conducted several training courses for CBP construction in Africa. A 1,000 litre biogas plant costs around US$ 200.

Photo on left: Director of the Appropriate Rural Technology Institute, Pune, India with ARTI's Compact Biogas Plant with plastic digester and plastic gas holder. Photo on right: the Biogas plant at the Biliza Biofuels Centre in Mozambique in which the digester is made of bricks and cement while the gas holder is made from a plastic water tank.

A well-constructed fixed dome digester made of bricks and cement can last for more than 20 years. For plastic bag digesters, the lifetime is generally taken to be 10 years, but there is not yet a definitive indication of lifetime in tropical countries. Units made of reinforced PVC have lasted more than 20 years in the Netherlands just out in the open. In the more severe conditions found in the tropics, bag digesters showed no signs of deterioration after exposure to sunlight for more than 1.5 years. If the fabric is shielded from direct sunlight, bag digesters will certainly last more than 10 years. (Frederiks, pers. comm.).

Both the fixed dome and plastic bag types of systems have their advantages and disadvantages. Fixed domes are robust (when properly constructed), built from locally-available materials, create employment, and are underground so take little space. Disadvantages are the costs, making them uneconomic under most conditions, and the need for properly-trained personnel for installation. Bag digesters are a lot cheaper and subject to economy of scale; they can be quickly installed with general technical skills, but they need to be imported – although local manufacturing is something that can be considered, if the right fabric is available. They take up more space and may have a shorter lifetime than the fixed dome. (Bart Frederiks, personal communication)

FACT Foundation has installed a number of plastic bag digesters in Indonesia, Mali, Mozambique, etc. The biogas in Mali is used to fuel the diesel engine of a multi-functional platform (MFP). In 2012, FACT installed 2 bag digesters (6 m3 and 60 m3) and 3 floating drum digesters (6 m3 each) at the Bilibiza Biofuels Centre (BBC) in Mozambique (Frederiks 2011). At BBC's generator house, the plastic gas holder type is used with Jatropha cake and dung, producing gas for the generator, for which the Chinese Lister type diesel engine (which was already modified to run on Jatropha PPO) was also adapted to use biogas as additional fuel. ADPP has reported that the system is used regularly and the experience shows good results. The H2S content was found to be negligible (<15 ppm). The behaviour of the engine under variable loads with gas input did not pose problems. (B. Frederiks).

A very good installation manual for both floating drum and the plastic plug flow digesters has been produced by FACT Foundation and ADPP based on their experience in Mozambique (FACT Foundation and ADPP – Clube de Agricultores 2012).

Engines developed for gas are commonly used in industrialised countries, but are often large units of several hundreds of kWs. Gas engines can run on 100% biogas (or producer gas from a wood gasifier) because they have spark ignition. A new power plant for biogas will usually select a gas engine. To use biogas in a diesel engine, either large or small, 15-20% diesel fuel is required because it is compression ignition and the biogas will not ignite under compression. The 15-20% diesel can be substituted by PPO since most plant oils have a Cetane Number high enough for igniting under compression.

Photo 8: Excavation of a 12 m³ Plastic Bag Digester ditch and daily feeding of the digester (Frederiks 2011)

Before using biogas in an internal combustion engine for shaft power applications or for electricity generation it may have to be purified. Carbon dioxide decreases the energy density of the gas but does not cause any problems in the engine. For small scale, in-situ applications, the costs of carbon dioxide removal are not justified.

Biogas from anaerobic digestion is usually saturated with water vapour (2-5% by mass) which also reduces the energy density of the gas. Since a relatively dry gas is better for engines, some form of passive water removal is generally incorporated, the simplest being cooling the gas followed by a condensate trap. Other methods of water removal such as absorption or adsorption are too expensive for small-scale applications (Petersson and Wellinger 2009).

Hydrogen sulphide (H2S), however, is corrosive because it forms an acid and can damage components such as gaskets and mechanical parts. Concentrations of H2S in raw biogas between 50 and 5000 ppm must be brought down to between 200 and 500 ppm for combustion of biogas in an internal combustion engine. Methods for H2S removal include biological fixation, iron chloride dosing, activated carbon and scrubbing with water or sodium hydroxide solution. The best method for small-scale application is passing the biogas through a media composed of woodchips and iron oxide or iron hydroxide. This process is reversible and the media can be regenerated by passing oxygen (air) through it. (BC Ministry of Environment 2010).

Rust-coated steel wool or pelleted 'red mud' (a by-product of aluminium production) have also been used. A study in Vietnam found that the locally available 'red mud' that contains iron oxide is the best material for removing hydrogen sulphide from biogas. The adsorption capacity of the red mud was found to be 5.45 mg H2S/1g red mud and 94.7% of H2S (2,500 ppm) was removed within 60 minutes. Since the red mud is available free of charge, there is no need to regenerate it (Huynh 2011).

It is expected that over the next 5 years, biogas production from Jatropha cake will be more widely practiced. To advance use of Jatropha cake for biogas production, the following R&D would be useful:

Photo 9: After pressing, almost all plant nutrients remain in the press cake. It is a good fertilizer.

- Lab trials on relation between cake composition and gas yield;
- Elementary analysis of different samples to check on presence of all required micronutrients;
- Operation on 100% Jatropha cake throughout the year.
- Monitoring of long-term effects of using biogas as a fuel in engines, maintenance problems faced, and solutions to address these issues.

Fertiliser

The Jatropha plant takes nutrients from the soil when it grows. Unless these nutrients are returned to the soil in one form or another, the soil will get depleted, the plants will suffer from nutrient deficiency and yields will decrease. Clean oil has close to zero plant nutrients so if sediment from filters and sedimentation tanks is returned with the press cake (after digestion) there is little loss of plant nutrients except for nitrogen, which can be compensated by intercropping with nitrogen fixing crops.

At most locations it does not make business sense to sell the press cake and buy fertiliser to compensate for the lost nutrients. On the other hand, there are logistical obstacles to bringing bulky press cake back to the farmers' fields, and farmers prefer to apply it to high-income crops like vegetables. The result is long-term depletion of the soil where the Jatropha grows and therefore reduced yields.

Using the press cake for biogas production does not reduce the nutrient content significantly. The slurry is some ways a better fertiliser than the unprocessed press cake, but is much more bulky due to the water content.

INIA in Peru has experienced some problems with the use of press cake as fertiliser because it is toxic and kills the worms that aerate and fertilise the soil (Prakash 2012). However, the main toxin, *phorbol* ester, takes about a week to break down in the soil and therefore does not pose any long-term environmental issues (Devappa, Makkar, and Becker 2010). This issue is covered in more detail in the chapter on "Health Issues".

The nutrient content of the press cake varies quite a lot depending on the growing conditions. That is to be expected and means that average figures may not be that useful for calculating amounts for specific localities. However, the exact nutrient content is not of interest when the press cake is returned to the Jatropha plants.

Fuel for Heating

Briquettes

The press cake has been used with good results for making briquettes to substitute for firewood, and these briquettes can be burned just like wood in industrial boilers. Use of briquettes in household cooking stoves is still not recommended, unless and until it has been proven that the smoke does not spread the typical toxic components of Jatropha oil, (e.g. curcin) into the air.

Research done by Wageningen University found that both Jatropha and tobacco briquettes produce more PACs (23-67 times), CxHy (2 times), NOx (3-5 times) and soot (4-13 times) than the Malawi reference charcoal. Only the CO production of Jatropha is more or less equal to that of Malawi reference charcoal and the CO production of tobacco briquettes is 4 times lower than for Malawi reference charcoal (Hamoen et al. 2011).

The recommendations for improved exhaust gas performance of both briquettes are the alteration of the briquette shape (smaller diameter or with a central hole in the briquette) and less

Figure 12: Briquetting press cake at Diligent in Arusha, Tanzania (photos: Krishna Raghavan)

compactness (less pressure applied), both of which changes would allow for more complete combustion.
The production of briquettes makes the most sense for large centralised oil-processing plants where logistics prevent the large quantity of press cake from being returned to the Jatropha fields.

Burning the press cakes produces a considerable amount of pungent smoke. To tackle this problem, Diligent in Tanzania has designed a charcoal kiln to make charcoal for the briquettes.

Pellets

Because the Jatropha oil has high value, Kiwia & Laustsen developed the Jiko Bomba stove that can burn pellets made of 2 parts rice husk mixed with 1 part Jatropha press cake.

Figure 13: Jatropha pellets and Pelletiser (photos: Dr. H. Rajabu and Bjarne Laustsen)

REDUCING FARMERS' PRODUCTION COSTS

In the previous chapter we showed that with the current Jatropha-derived products, the farm gate price for a kilo of Jatropha seeds is moderate. This is of course dependent on the price of mineral diesel, and this price may improve. As long as this price does not increase, product diversification can increase the value of Jatropha seeds and therefore the farm gate price. In this chapter, we will look at what production costs have been experienced so far, what has been learned about how they can be reduced, and finally, what cost reductions can be expected over the coming five years due to progress in agronomy, breeding and mechanisation.

Production Costs Experienced so far

The data on production costs is limited and imprecise. The hedgerow systems of small farmers in marginal areas that are the main focus of this publication are hardly documented.

Still, we have a basic understanding of what costs are important and how the importance of different tasks changes throughout the lifetime of a Jatropha system.

The costs to farmers can be divided into land, capital and labour costs. Since we focus on areas without land shortage, only capital and labour will be considered. Of the two, labour is the important one as no mechanisation, fertiliser, pesticides or irrigation are generally applied. Labour is mostly provided by family members.

When labour does not involve cash transactions, it is difficult to make a proper assessment of production costs. In research, working hours are often used as a proxy, but in agricultural systems with a marked seasonality, the real cost to farmers varies per season. To farmers, the cost of for instance ten extra working hours is close to zero if the work takes place during the dry season.

However, ten extra working hours during the planting or harvesting season carries a high price for farmers. In economic terminology, the opportunity costs are high. There are many additional factors that undermine the value of labour hour measurements and many of them pull in opposite directions. An example from the Hivos-supported Jatropha project in Northern Mozambique illustrates this point well: farmers were encouraged to harvest Jatropha only after harvesting their food crops. However, many preferred to mix the two and explained that harvesting the food crops is hard physical work due to the digging involved. As a result, , they need to alternate with more 'relaxing' tasks during the working day. Harvesting Jatropha is a nice way to take a 'break' because of the lightness of the work and the shade of the bushes. Despite taking place during the peak labour season, the opportunity cost to the farmer is close to zero, which is the opposite of what would be expected when seasonality is considered.

If the farmer instead decides to hire labour for harvesting the Jatropha, the costs will be about the highest experienced all year because there is a shortage of labour during the harvesting season. It is thus clear that the answer to the question "What is the cost of harvesting Jatropha?" is not that easy to answer even when working hours are known.

Realising the shortcomings of the various methods of assessing the value of labour used by smallholders, several studies have opted to allocate zero value to family labour. Table 5 is an example taken from the well-known study of Jatropha and other oil plants in Kenya (Liyama et al. 2009). For commercial Jatropha production, they included costs for most farming tasks. As a result, several economic analyses of different Jatropha systems overestimate the benefits of Jatropha to smallholders.

The value of family labour is in practice impossible to assess in a meaningful way as it depends on the opportunity costs that vary over time and with context.

Many studies have opted to exclude the cost of family labour. However, for a crop like Jatropha where the main cost to the farmer is labour, such a simplification creates bias of an unknown magnitude.

Only implementation in the field can reliably tell how attractive Jatropha is compared to other crops.

To be able to make meaningful comparisons, some studies use zero opportunity costs for all systems being compared. For instance, van Eijck et al. used this approach when they compared energy crops in Tanzania; they concluded that for farmers who cannot wait for an income, cassava is the best option whereas eucalyptus and Jatropha are options for farmers who can wait a number of years (Eijck, Smeets, and Faaij 2012)[19].

Only implementation in the field, such as the pilot projects supported by Hivos and FACT, can give sufficient insight into the costs and benefits to farmers. This is because farmers will opt for the combination of crops that match their priorities.

For a crop with a productive life of 20+ years, a meaningful assessment of production costs must cover more than the first few years. Some of the significant production costs occur during the start-up phase, but only once in the lifetime of the system.

Initially, the major costs are for planting material and land preparation. In some localities, seedlings can be obtained from commercial or government nurseries. However, in some of the marginal areas where Jatropha has a high potential, these services are not available. As a result, farmers have to construct and run nurseries themselves unless they opt for direct seeding.

In many areas of Asia and South America, farmers are accustomed to managing small nurseries; but in marginal areas in Africa this is rarely the case and it is therefore a bigger hurdle to overcome, meaning that both quality and productivity may be low.

Most nurseries have been relatively elaborate structures producing polybag seedlings. However, experience has shown that bare-root Jatropha seedlings perform well and that shading in the nurseries can vary a lot without affecting the seedlings. Furthermore the seedlings are not very sensitive to rough handling and even to drying out on the back of a bicycle when transported to the fields.

In many cases, seeds and seedlings have been provided or subsidised by Jatropha projects. In Asia, planting material has in many cases been given on credit.

Seeds for sowing are usually sold at a higher price than seeds for oil production. However, even with a price of €1/kg, seeds for one hectare at 2.5 x 3 m spacing with 50% replanting will cost no more than €1.2 (Putten et al. 2010, 15). Seed costs are therefore an insignificant part of the production costs.

During the peak of the Jatropha hype, there was a shortage of seeds and some farmers were willing to pay very high prices for seeds. A survey in Kenya found that farmers had paid around 775 KSH/kg (ca. $11 US/kg) in 2006-2007 (Liyama et al. 2009, 43). Even at this inflated level the cost of planting one hectare is less than $13 US, but for farmers that use minimum input and rely on family labour, seed costs this high can be an important start-up cost as shown in Table 5.

Seed is a minor expense for farmers planting Jatropha.
Seeds have in many cases been subsidised by projects or governments.

Reported prices for seedlings vary from zero to about €0.10 (Raju et al. 2012, 55). That would entail a cost of up to $200 US per hectare with a spacing of 2.5 x 3 m and a replanting rate of 12.5%. At this price, seedlings become an important part of the costs of starting Jatropha cultivation.

Farmers in areas with a distinct dry season and no access to irrigation have a low workload during the dry season when seedlings are produced. The cost to the farmers of running a Jatropha nursery is therefore low and it makes sense to produce seedlings instead of purchasing them.

The time for the initial land preparation is similar or lower than for other crops and unlike annual crops, it is only incurred once. Where farmers have opted to only clear and dig the soil at the planting station, land preparation time is very low.

19 The study by Janske van Eijck et al. (Eijck, Smeets, and Faaij 2012) uses Jatropha data from (Liyama et al. 2009) which are collected in areas where the agro-climatic conditions are poor for Jatropha (Trabucco et al. 2010), whereas data for eucalyptus and cassava are from areas suited to these crops. This introduces some bias in the comparisons.

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

Table 5: 10-year production costs for one-acre Jatropha fence in Kenya; smallholder scenario (Liyama et al. 2009, 45)

Photo 10: Jatropha pruned with a machete. The poor cut leaves entry points for infections and decay

Particulars	Rajasthan			Chhattisgarh			Uttarakhand		
	I year	II year	III year onwards	I year	II year	III year onwards	I year	II year	III year onwards
Land preparation	1125	0	0	375	0	0	900	0	0
Digging pits	5625	0	0	2125	0	0	4800	0	0
Sapling cost	11250	1500	0	1065	225	0	0	0	0
Planting	3000	375	0	1125	375	0	2400	0	0
Manuring	3125	0	0	2375	0	0	2400	0	0
Fertilizer	3325	0	0	0	0	0	0	0	0
Irrigation	1000	1000	1000	500	0	0	500	0	0
Harvesting	0	0	6750	0	0	2500	0	0	5400
Sub-total	28450	2875	7750	7565	600	2500	11000	0	5400
Incidentals (-10%)	2845	288	775	756	60	250	1050	0	540
Total cost	31295	3163	8525	8321	660	2750	12050	0	5940
Returns	0	0	17812	0	0	17875	0	0	13500
Net profit	-31295	-3163	9288	-8321	-660	15125	-12050	0	7560

Notes: *The figures are averages across sample farmers.*
Wages: *Rs 150, Rs 50 and Rs 120 for Rajasthan, Chhattisgarh and Uttarakhand, respectively.*
Cost of saplings: *Rs 6.00 and Rs 0.50 per seedling in Rajasthan and Chhattisgarh, respectively, 100 per cent subsidized in Uttarakhand.*
Cost of fertilizer: *Rs 9.50/kg of DAP and manure @ Rs 500 per tonne.*
Cost of irrigation: *Rs 500 per irrigation per hectare*
Price of Jatropha seeds: *Rs 7.50/kg in Rajasthan, Rs 6.50/kg in Chhattisgarh and Rs 6.00/kg in Uttarakhand including overhead charges on seed collection.*

Table 6: Economic analysis of Jatropha cultivation in selected states of India. Source: (Raju et al. 2012, 55)

Only at localities with hard pans can the digging of the planting pits require more labour than land preparation for other crops. At most localities, some replanting has been required during the first and second year.

Until the canopy closes and out-shades weeds, regular weeding is required. Jatropha is sturdy and will usually survive being covered in weeds but it will not develop. It provides some resilience; for example, farmers can concentrate on critical and sensitive crops while postponing the weeding of Jatropha without losing the plants.

Weeding Jatropha is easy compared to other crops due to the low density of plants and their distinct look that makes them easy to identify.

Formative pruning should be done during the first few years to increase branching and thereby yield. Later, annual maintenance pruning is required to keep the plants short enough for easy harvesting. Jatropha wood is light and easy to cut, so pruning is fast. Pruning by slashing with machetes is common although not recommended due to the rough cuts and splits in end branches that commonly occur. They become entry points for infections.

In Mozambique, commercial plantations have experimented with tractor boom movers for very rapid pruning of Jatropha hedges. It is very efficient but also results in split branches. Still, no negative effects were observed on the performance of the hedges (pers. comm. Jon McLea, Energem).

After the first few years, the weeding requirement is minimal and the major production costs become harvesting and de-hulling of seeds. Since these are recurring costs, they dominate the production costs seen over the lifetime of a Jatropha system.

At several locations, production costs have been reported for fertiliser, pesticides and irrigation. However, as discussed earlier, this should generally be avoided as it makes Jatropha production uneconomical. In depleted soils, initial fertiliser application may be required, but the long-term soil fertility should be ensured by returning the press cake or slurry to the fields, thus creating a closed nutrient loop.

In Table 6, average production costs from 180 farmers in three states in India are shown. Hired labour was used for all operations except weeding and pruning.

A net profit was achieved in the third year in all cases, but due to the high initial investment costs it will take several more years before the break-even point is reached. It is also questionable whether it is correct to allocate no costs for weeding and pruning: farmers have access to irrigation so the weeding and pruning of Jatropha competes with other activities no matter what time of the year they are performed.

Wages in Chhattisgarh are less than half of the other states but there they still achieve lower net profit due to the lower yield. Notice that this tells little about the viability of Jatropha production which will depend on the profit of alternative crops. The areas with the lowest net profit may very well be the areas where Jatropha is most attractive to farmers.

Photo 11: Drying rack for Jatropha seeds meant for sowing, Niasa, Mozambique

Harvesting Costs

Since harvesting is by far the major cost of Jatropha production over a full cropping cycle, the efficiency and options for mechanisation are important factors in assessing the viability of Jatropha.

Harvesting consists of picking, de-hulling and drying if the moisture content is above six per cent. Almost everywhere, dry seed is the product delivered by the farmer. This keeps transport and processing costs down. However, it may very well be that the whole value chain can be more profitable by making de-hulling and/or drying part of the processing, making it possible to take advantage of efficient machinery and processes that are out of reach for individual farmers.

At many locations, drying is not required. Where drying takes place, the costs vary widely depending on weather and the equipment used. If the seeds are used for oil production, drying in direct sunlight is fine; but if they are to be used for sowing then shade is recommended. Small farmers often sun-dry seeds directly on the ground or on plastic sheets.

Picking of Jatropha is always done manually. The uneven maturation, with fruits at different development stages appearing in the same bunch, makes it difficult to mechanise harvesting and slows manual harvesting. It also means that the same plants must be harvested several times a year. Harvesting three times is common.

Mechanical harvesters are in development. They are expensive self-propelled machines targeting plantations, i.e. monocropped uniform plants on non-sloping ground2. We are not aware of any work on small mechanical harvesters suitable for individual farmers and for non-uniform conditions. Manual harvesting is therefore likely to be the common way of harvesting the coming five years and beyond.

Reported harvesting rates vary significantly. Since they are mostly measured in fields with young Jatropha plants that don't have much yield yet, they are likely to be lower than what we can expect in mature Jatropha.

In Bajo Mayo, Ecuador, farmers harvested 25 kg in 8 hours and used the same amount of time to de-hull the crop. With a sales price of $0.27 US/kg that provides less than half of the minimum salary (Veen 2011, 15).

In Mozambique, we also found that de-hulling takes about as long as picking the fruits (Nielsen 2009b). Farmers were able to pick up to 42 kg in 8 hours and needed almost the same amount of time for de-hulling. The daily income at the high picking rate was about double the common day rate for manual labour in the area. The farmers who were the slowest earned about two-thirds the rate for manual labour (Nielsen 2009b).

> *Manual picking rates are typically 40 to 60 kg per day in Jatropha that yield 500 kg/ha or more.*
>
> *Manual de-hulling requires almost as much time as picking.*

Manual picking rates compiled by FACT are typically between 40 and 60 kg of seeds per day (Putten et al. 2010). We consider this range realistic under typical scenarios for Jatropha that yields 500 kg/ha or more.

Much lower figures have been reported in a number of studies, but they appear mostly to have been obtained in immature plants or in areas with low yield. In Indonesia, Mirco found that it took a day to pick just 10 kg of seeds because the plants had not been pruned and the Jatropha had grown to a height of three metres (Mirco 2012, 144).

Higher rates (e.g. up to 144 kg of seeds per day) have been reported. These may be obtainable by fast pickers in plantation settings but should not be expected under typical smallholder conditions.

Optimise Current Jatropha Cultivation Systems

Jatropha cultivation is still in an experimental stage. Decisions about planting time, planting material, pruning regime, soil preparation, planting distance etc. are still 'best guesses' based on limited experience.

It is not unlikely that in some cases, current best practices will be proven wrong when more rigid research is done. One example may be pruning, where there has been wide agreement about early and regular pruning being essential for high yields. Recently, some including Quinvita (pers. comm.) have concluded that this is not the case.

Some organisations like FACT Foundation have been documenting current best practices in detail (Putten et al. 2010; de Jongh and Nielsen 2011), so only selected issues are covered here. These include issues affecting the viability of Jatropha production, issues that are often misunderstood, and issues that urgently require more research.

Yield Gap

Much of the discussion around the collapse of the Jatropha hype has focused on the gap between expected and actual yields. There are many dimensions to this discussion, including:

- Disagreements about how long it takes for Jatropha to mature and reach full yield;

Photo 12: Farmer harvesting Jatropha in Mozambique

- Disagreements about the growth curve for Jatropha yield, i.e. how does the yield develop between planting time and maturity;
- Uncertainty about yield that will be achieved at maturity, and;
- Misunderstandings, deliberate distortion, lack of due diligence.

Because there are hardly any localities where cultivated Jatropha has reached maturity, the expectations as to the yield at maturity are largely based on assumptions about how the yield develops over time. If yields are low during the first years but then pick up rapidly towards maturity, then low yields after three years may not be anything to worry about. However, if the yield is close to maximum after three years, then the story is very different.

In the coming years when more data on the yield of mature Jatropha begins to emerge, the growth curves will become less important for assessing the yield potential of Jatropha but will remain important for timing investments in processing facilities and supporting infrastructure. Until now, many processing facilities have been established years before there was sufficient Jatropha to feed them.

The third reason for failed yield estimations, namely misunderstandings, has been covered earlier. Jatropha is a new crop and knowledge is limited. However, there was sufficient knowledge at the beginning of the recent Jatropha hype to prevent many of the mistakes that were eventually made. In many cases this must be attributed to lack of due diligence, and in some cases to vested interests.

Growth Curve for Jatropha

To establish the growth curve for Jatropha, regular measurements must be taken from the same plot, from the first harvest till maturity has been reached. Unfortunately there are few long-term data series available on Jatropha seed yield. One data series that covers the full period from establishment to maturity, when the yield levels off, is a nine-year data series from Paraguay reported back in 1985 (Matsuno et al. 1985).

The Paraguay data series exhibits the generalised logistic curve, also known as a Richards curve, which is commonly observed in plant development. Nielsen estimated the parameters for the Richards curve (Nielsen 2009a). The curve, as well as the Paraguay data points, is included in Appendix A. They follow a classical S-curve.

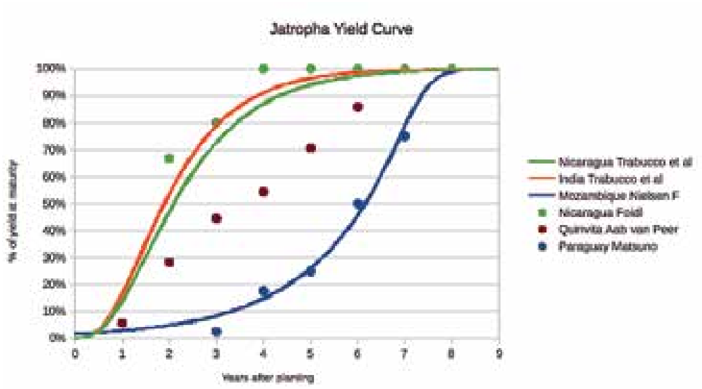


Figure 14: Different Jatropha yield curves and the data on which they are based.

Trabucco et al. (2010, 143) analysed one data series by Foidl (1996) in addition to their own data from Allahabad, India and also found that the Jatropha yield can be described with a Richards curve. However the parameters are very different, as can be seen from Figure 18. Instead of an S-curve with a slow initial increase in yield, they found that a big part of the final yield is reached in just a few years.

Finally, a data series measured by Quinvita (Ab van Peer, pers. comm.) is included. It indicates a linear growth curve which falls in between the other curves.

It is unlikely that all the curves are right. Unfortunately, there are uncertainties about all the curves. A detailed review of the curves and the data behind them is provided in Appendix A.

This leaves us in the unfortunate situation of being unable to determine the typical growth curve for Jatropha. Also, there is insufficient data to determine how long it takes for Jatropha to reach maturity.

How Low is Low Yield?

It is often stated that the Jatropha yields are too low. However, a yield figure without context is meaningless:

A Jatropha yield of 800 kg/ha is high for an African farmer who is harvesting 450 kg/ha of maize, but low for a farmer who is harvesting 3,000 kg/ha of maize.

As argued elsewhere in this document, yield per hectare is less important in areas with abundant land. However, there are some advantages to higher yield per hectare:
Less land must be prepared and later weeded. This is important during the start-up phase, but as shown above, the major time spent on Jatropha over its lifetime is for harvesting.

If the yield is low, too much time is spent by the farmers moving between plants and searching for ripe seeds. However, for any crop, manual harvesting efficiency levels off when a certain yield level is reached.

Borman et al. (2012) plotted harvest efficiency data against the yield and derived the curves shown in Figure 14. There are many assumptions behind the figures and although the data pairs on efficiency and yield are from the same locations, they were not measured in the same fields and at the same time. As more data become available, the exact figures may change but the shape of the curve is likely to remain valid.

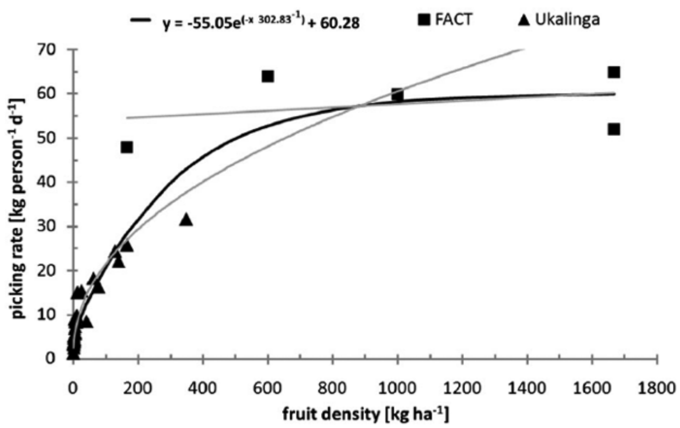


Figure 15: Rate of picking (seed) as a function of fruit density during harvest. (Borman et al. 2012)

Beyond a yield of 800 kg/ha, there is little gained in harvesting efficiency and thus in production costs. Doubling the yield to 1,600 kg/ha can cut the time spent on weeding and pruning in half. However, since this accounts for typically 10% of the labour, it only increases the return to labour by 5%.

Increasing the yield beyond 800 kg/ha has minimal effect on the return to labour: doubling the yield only saves 5% labour.

Enhance Jatropha Productions

The analysis above makes it clear that any significant reduction in production costs has to come from increased efficiency in harvesting and de-hulling.
Harvesting efficiency can primarily be improved through breeding or mechanisation. In the foreseeable future most progress is likely to come from breeding, which is still in its infancy.

Mechanisation can improve de-hulling efficiency significantly. Equipment is already available and at a price that is accessible to some farmers or groups of farmers.

Genetic Improvement

So-called 'improved' Jatropha seeds have been on the market since the Jatropha hype started. However, they are usually just seeds collected from high-performing plants and the performance is not very different from 'unimproved' seeds. In many cases the experience has been that seeds collected locally perform at least as well as any commercial seeds. Real genetic improvement of Jatropha has started but is still in its infancy.

Several approaches to genetic improvement of *Jatropha curcas* are currently being pursued, including traditional breeding, heterosis breeding, mutation breeding, interspecific hybridisation and genetic transformation. Because there has been no breeding work on Jatropha so far, it is generally expected that relatively large gains can be achieved quickly and with modest resources. Improved planting material developed through traditional and heterosis breeding is currently being field tested by several companies and farmers. The overriding objective is a reliable yield of 6-8 t/ha followed by a list of secondary objectives like early maturation, pest and drought resistance, non-toxicity, and synchronised ripening of the seeds (Hawkins and Chen 2012). The major companies include jOil, Quinvita, Jatoil, Jatropower and SG Biofuels (SGB). However, there are also farmers and small companies that invest in breeding and claim to have some success. One example is Bionic Palm[20] in Ghana. Some public research centres and universities have Jatropha breeding programs too. Most of the companies mentioned have employed leading scientists from public research institutions.

Until recently the lack of male sterile plants meant that heterosis breeding was expensive to scale up (Tar, Tanya, and Srinives 2011, 592). However, it appears that SGB has identified male sterile plants which they are now trying to patent (Rotter 2012) even though it appears to be a regular natural phenomena. Bionic Palm claim to have collected male sterile plants on their own and strongly oppose the patent claim (Bionic Palm 2013).

The private companies are all claiming they are making rapid progress. However, they do not share enough information to make it possible for outsiders to verify their claims. For instance SGB claim that their hybrids consistently perform 400-500% better than commercial varieties (Marketwire 2013), which sounds very unlikely. Still, given that the evidence from university-based research indicates that heterosis breeding is easy and yields good results, it is highly likely that several companies are indeed close to releasing improved planting material to the market. Hawkins and Chen (2012) assess that the yield improvement from 2012 till 2020 will be about 15%.

The impact of improved seeds is however likely to be modest for poor smallholders, not only because of the high price that will likely be charged, but because the yield under smallholder conditions is mostly limited by non-genetic factors like soil nutrients, water and agronomic practices.

Interspecific hybridisation has been achieved by several people working in the field as well as on research stations (Parthiban, Kumar, and Thiyagarajan 2009). Some hybrids have seeds significantly larger than *Jatropha curcas* but yields are usually lower. For smallholders that spend most of their time on harvesting and de-hulling Jatropha seeds, larger seeds can significantly increase their productivity. As argued elsewhere in this chapter, yields above 800 kg/ha have little impact on farmers' productivity and they can therefore gain from larger seeds even if the yield per hectare is lower than unimproved seeds.

Unfortunately there appears to be hardly any field testing of interspecific hybrids under way and it is therefore unlikely that any interspecific hybrids will have any impact over the coming five years.

Genetic transformation has the highest potential for improving Jatropha genetics but is also the most demanding and the most expensive approach, as well as the slowest one to implement. The experience from other GMOs is that it takes 15-20 years from when the research begins until seeds are available on the market, and it is therefore unlikely to have any impact over the coming five years.

Mechanisation

De-huller

To reduce the labour required for post-harvest processing, the de-hulling can be mechanised. Manual shelling can damage the seeds, and is therefore not suited for producing quality seed material. Manual shelling has an average rate of 4 kg per hour, whereas a hand-operated shelling machine can increase the rate to 30 kg

20 http://bionic-enterprises.com/bionic-companies/bionic-palm-limited/

Photo 13: Manual de-hulling of Jatropha seeds is labour-intensive. Simple mechanised de-hullers can reduce production costs significantly.

per hour and a pedal-operated de-huller can increase productivity further to 200 kg per hour. A large-sized industrial-type de-huller would be able to process up to 500 kgs of seed per hour.

Different designs of mechanical hand-powered de-hullers have been tested with varying degrees of success. In Honduras, farmers found that they could hull just as fast by hand as they could with a 'Nicaraguan' mechanical huller. One of the most effective hand-operated shelling machines is the 'Universal Nut Sheller' which was developed for shelling peanuts in Africa under the Full Belly project (http://www.thefullbellyproject.org). This sheller can be adjusted for any size of nut and it has been used for shelling /de-hulling coffee, shea and Jatropha seeds. It is now being locally manufactured and sold for de-hulling Jatropha seeds by Gota Verde in Honduras, Jatropha Pepenye in Haiti and Mali Biocarburant in Mali.

This Universal Nut Sheller is made of concrete and steel and is fairly simple to fabricate locally. It needs about $30 US for materials and 2 days of labour to prepare the metal pieces, pour concrete into moulds and assemble. No maintenance is required but the cement bell can break easily if it falls. BYSA conducts Training Programs to teach local entrepreneurs to fabricate and assemble the de-huller (Moers 2010; Putten et al. 2010).

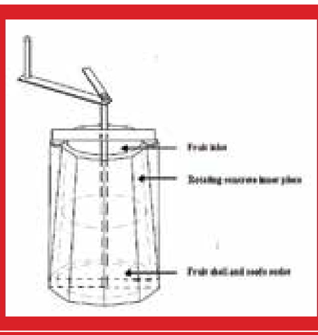
The know-how to manufacture this de-huller locally could easily be transferred to other countries to improve productivity of farmers. Further development work on Jatropha de-hullers is likely to lead to improved designs that have a higher output, lower cost of production and less chance of breakage. One such innovation is the 'Pedal Platform', also developed by Full Belly, which can be fitted with a growing number of attachments to increase the productivity of common agricultural processes – two human legs have eight times the power of one human arm. The Pedal Platform connected to the Universal Nut Sheller is shown in Figure 16.

Motorised de-hullers at central processing facilities provide an option that looks promising but still needs further development and testing. A mechanical Jatropha de-huller has been designed and fabricated by a technical school in Nicaragua. In Peru, DRASAM developed an electric de-huller in collaboration with a local technical education institute, based on a Brazilian coffee de-huller. This model has a capacity of 100 kg/hour and cracks the dried fruit and separates the seeds from the hull using a blower with a separation efficiency of 97%. The local production cost of this machine is $ 1,600 US. It runs on electricity but can be adapted to run on an engine using diesel or PPO (Prakash 2012).

An industrial Jatropha de-huller designed under 'Proyecto Tempate'[21] in the Leon region of Nicaragua consists of a

21 "Proyecto Tempate" was a joint project of the Governments of Nicaragua and Austria which ran from 1991 to 1999 to demonstrate Jatropha for biofuels.

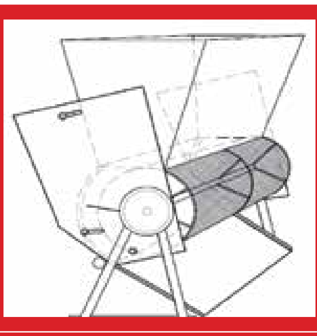
Universal Nut Sheller



Universal Nut Sheller

Pedal Platform connected to the Universal Nut Sheller

Figure 16: The Universal Nut Sheller (http://www.thefullbellyproject.org/Products.aspx)



Pellets made of rice husk and Jatropha press cake

Jatropha Pelletiser

Figure 17: A high-capacity motorised Jatropha de-huller developed under Proyecto Tempate in Nicaragua (FACT 2010)

Photo 14: Vibrating Sieve used to sort and clean Jatropha seeds at Diligent in Arusha, Tanzania

horizontal mesh cylinder rotating at 100 rpm which presses the fruit against a fixed mesh on the upper side adjusted to optimise the process. The de-huller and the separator are driven by an 8 HP diesel engine that consumes 0.75 litres of fuel per hour. The machine has a capacity of up to 500 kg of seeds per hour, weighs 120 kg and costs around $2000 US (Putten et al. 2010).

The Universal Nut Sheller operated by hand or with the pedal platform is a low-cost option to increase productivity that can be manufactured locally; moreover, it will provide employment to a larger number of people. On the other hand, larger Jatropha processing facilities will prefer to use the more expensive, high-capacity, industrial type de-huller that is motorised with a diesel engine or an electric motor.

Vibrating Sieve

Quality seed material requires the selection of the biggest seeds, and they need to have been de-hulled with no damage to the seeds. Both of these processes can be mechanised for higher productivity. A Vibrating Sieve used to sort seeds according to size is shown in the photo. The machine has two sloping vibrating screens – the top screen holds the larger seeds while the bottom screen carries the smaller seeds to the right of the photo where they fall on the ground. Small stones, fine dirt and sand pass through the lower sieve and collect in the yellow bag hanging behind the right leg of the sieve. The metal frame holding the screens is vibrated by a motor. Larger stones, sticks, etc. of similar size to Jatropha seeds have to be removed manually. This type of vibrating sieve can easily be fabricated locally.

Mechanical Harvesting

Mechanical harvesting is difficult because flowers and seeds at various stages of maturity grow simultaneously. Several companies have developed mechanical harvesters for Jatropha based on the harvesters used for berries and olives and have conducted field trials in Jatropha-growing countries:

- BEI International (USA): model *BEI Jatropha Wave Harvester* in Honduras (Lint 2009).
- Rakennustempo Oy/Joonas International (Finland): model *Joonas FH Jatropha harvester* in Ghana and Mozambique (Sandholm 2010)
- Oxbo International (USA): model *Korvan 9000* in Costa Rica (Korthuis 2010).

Photo 15: Joonas FH Jatropha harvester trials in Mozambique. (http://rakennustempo.fi/)

The ripe fruit is harvested while leaving the green fruit on the plant. To allow enough space for the harvester to operate in the Jatropha fields, important considerations are:

1. From the centre of one row to the centre of the next row should be a distance of at least 3 metres.
2. Plants within rows should be spaced at around 1.5 – 2 metres apart.
3. There should be free space of 7.5 metres at the end of each row to allow the harvester to turn into the next row.

Harvesters typically cover 0.8 – 1.0 hectares per hour depending on field conditions. The *BEI Jatropha Wave Harvester* which costs $180,000 US has been used at the 550 acre Jatropha plantation of Agroipsa in Honduras. BEI also provides a 'bolt-on' Pruning Kit that allows the harvester to be used for mechanised pruning of the Jatropha plants, either with the harvest or at other regular intervals. A mechanical harvester could be financially viable for a large number of small farmers, grouped in a co-operative for example.

Photo 16: Bolt-on Pruning Kit for the BEI Jatropha Wave Harvester. (http://beiintl.com, Lint 2009)

Mycorrhizal inoculation

Mycorrhizal inoculations are commonly used in agriculture and forestry to improve the capacity of plants to absorb nutrients and water, which leads to higher yields and a faster ramping up of production. Research on *Jatropha curcas* has been conducted in several countries, including Thailand, the Philippines, India and Brazil, and shows that arbuscular mycorrhizal (AM) fungi inoculations can increase the tolerance to salt and drought, increase the growth rate and shorten the time to fruiting (Ultra 2009; Kumar, Sharma, and Mishra 2010; Kamalvanshi et al. 2012; Balota, Machineski, and Scherer 2012). Tewari (2007) found that inoculating Jatropha increased biomass and yield by 30%.

Several companies have been selling AM inoculations for Jatropha on the internet. These mostly contain unidentified AM species that may not be optimal for Jatropha and the effect is therefore uncertain. The situation is comparable to that of the Jatropha seed market: a lack of technical standards and quality controls makes it hit-or-miss. Only local testing will show what works. Since both seeds and mycorrhizal inoculates are cheap and the potential gains large, it is nonetheless worth testing.

Carbon Financing

Another way in which value can be added to the Jatropha production chain is for carbon credits to be produced and sold. There are two ways in which the Jatropha production chain can generate carbon credits. First, Jatropha trees act as carbon sinks in that they absorb atmospheric carbon dioxide and store it in their biomass and surrounding soil, a process known as carbon sequestration. Second, where Jatropha biofuels are used to replace fossil fuels, carbon credits can be claimed for the replaced fuel.

To determine the total amount of carbon credits that can be produced from a Jatropha project, leakage emissions also have to be taken into account. Leakage emissions, in the case of the Jatropha production chain, can be divided into two categories. The first of these is emissions that arise as a result of converting land from one use to another. The second is emissions brought about by the use of inputs, such as fossil fuels and fertilisers, on the project site.

The amount of carbon credits that can be produced from substituting fossil fuels with Jatropha biofuels is closely related to seed yields seeing as, all other things being equal, higher yields translate into higher biofuel production volumes (Wouter M.J. Achten et al. 2010). If an average yield of 1500 kilos of seeds per hectare is assumed, and furthermore that it takes 5 kilos of seeds to produce 1 litre of Jatropha biofuel, it follows that 300 litres of biofuel can be produced per hectare, which, if it is used to replace fossil diesel, entails a reduction of 960 kilos of carbon dioxide emissions, which equals just about one carbon credit.

To determine how many carbon credits can be produced from carbon sequestration, it is necessary to calculate the difference between the amount of carbon dioxide stored in biomass and soil before and after the Jatropha has been planted. To date, only a handful of studies have attempted to estimate the carbon stocks of mature Jatropha plantations. Hellings et al. (Bart F. Hellings, Henny A. Romijn, and Ywe Jan Franken 2012) studied the carbon sequestration properties of mature Jatropha trees planted on marginal land in Tanzania and estimated that one hectare of Jatropha trees sequesters 20 tonnes of carbon dioxide. Another study set out to model the carbon stocks of Jatropha trees planted on marginal land in Burkina Faso and reached an estimate of 25 tonnes of carbon dioxide per hectare (Nielsen 2012). Achten et al. (2012) tried to model the carbon debts associated with Jatropha plantations under different land use change scenarios, and in their calculations they assumed that a mature Jatropha plantation sequesters between 48 and 74 tonnes of carbon dioxide per hectare, although it is not clear how the authors obtained this range (W.M.J. Achten et al. 2012). Comparing the results of the studies discussed above is difficult as they all drew on different methodologies and assumptions. For instance, the study by Nielsen includes pools of soil organic carbon in its analysis, whereas those by Hellings et al. and Achten et al. do not. Under the assumption that the carbon stock of one hectare planted with mature Jatropha trees is 20 tonnes of carbon dioxide, it can be deduced that emissions reductions from carbon sequestration are only possible in the specific case that the Jatropha is planted on land with low carbon stock. The carbon debt incurred by planting Jatropha on land with high carbon stocks could, in theory, be repaid through the production of Jatropha biofuel (which is used to replace fossil fuels) but at current yields, repaying such a debt in this way would take hundreds of years which is not a realistic or attractive proposition.

All other things being equal, low input farming systems produce less leakage emissions than input-intensive farming systems, with the application of chemical nitrogen fertiliser having a particularly detrimental effect on the greenhouse gas balance of the Jatropha production chain (Kim, Kim, and Dale 2009). As discussed earlier, returning the press cake to the fields either directly or as slurry after biogas production ensures a closed nutrient loop for all plant nutrients except nitrogen, which can be replaced by intercropping with nitrogen-fixing plants.

If it is assumed that Jatropha is planted on marginal land with a carbon stock of 5 tonnes per hectare and that the carbon stock of a mature Jatropha plantation is 20 tonnes per hectare, it follows that 15 tonnes of greenhouse gas emissions are saved per hectare of land planted with Jatropha. Furthermore, if it is also assumed that the lifespan of a Jatropha plantation is 20 years, and that the average yield is 1500 kilos of seeds per hectare, it can be deduced that an additional 19 tonnes of carbon dioxide emissions can be saved by replacing fossil fuels with Jatropha biofuel. Assuming that 10% of these emissions reductions are lost through leakage emissions due to the use of inputs on the project site, it follows that the greenhouse gas balance of a Jatropha plantation is 35 tonnes of carbon dioxide per hectare. Given a price of €6 per carbon credit, this translates into revenues of €210 per hectare over the life span of a Jatropha plantation.

Country	Developer	Market	Size (MT)	Status
Congo	Carbon2green	Compliance	219,4259	Cancelled
Madagascar	JatroSolutions	Compliance	26,797	Cancelled
Mali	Eco-Carbone	Voluntary	400,000	VCS certified
Mali	BERL	Voluntary	34,520	VCS certified
Mali	Mali Biocarburant	Voluntary	88,000	Uncertified
Uganda	Global-woods	Voluntary	200,000	CarbonFix certified

Table 7: Overview of Jatropha-related carbon credit projects

Carbon credits can be sold on the compliance or voluntary carbon markets. Credits sold on the compliance market must be CDM certified. While CDM certification is not required to sell credits on the voluntary market, it could be argued that certification is required in practice, as most buyers want to be sure that the credits they purchase represent actual reductions in greenhouse gas emissions. For a Jatropha project to get certified it needs to meet this additional criterion, meaning that the project would not be economically feasible in the absence of carbon financing. Another requirement is that there is no double counting, which is to say that a given reduction in emissions can only be claimed once. In addition to this, projects also need to demonstrate that they have no adverse impacts on the environment as well as on the livelihoods of stakeholders. Farming systems built around intercropping meet these requirements as they do not endanger local food security through competition for land and have a low environmental impact, but this is less likely to hold true for monocrop plantations where competing claims for land, as well as threats to biodiversity, become more pronounced.

The extent to which it is feasible for a Jatropha project to produce and sell carbon credits is heavily dependent on the cost of obtaining certification and the price carbon credits fetch on the market. Regarding the costs of getting a project certified, they tend to be very steep; consultants need to be hired, inspections need to be carried out and administrative costs must be covered. As for carbon credit prices, they are currently at an all-time low and there are no signs of prices rising within the foreseeable future. The combination of high certification costs and low permit prices means that economies of scale play a significant role in determining whether or not it is feasible for a Jatropha project to produce and sell carbon credits. However, this might be about to change as most certification schemes are developing special provisions for small-scale projects that include less stringent monitoring requirements and the possibility of pooling multiple small projects into one application.

The point at which carbon credits are paid for has a large bearing on the degree to which carbon financing can play a role in realising the potential of Jatropha for local development. Clearly, from the project developer's point of view, the ideal option is for credits to be paid for at the beginning of a project, as it is at that stage of the project life cycle that capital is most likely to be scarce. However, at present the prevailing modus operandi is for carbon credits to be sold after they have been produced, although a few certification schemes offer project developers the option to get paid up-front (albeit with the caveat that credits paid for up-front tend to sell for less than credits which represent emissions reductions that have been realised).

Hivos did not attempt to generate carbon credits from any of its Jatropha pilot projects but a number of other Jatropha projects have attempted to do so, some of which have been successful. An overview of these projects is provided in the table below.

As can be deduced from the table above, no Jatropha projects have sold carbon credits on the compliance market (CDM, 2012), for which there are several reasons. First of all, CDM certification is much costlier than the voluntary certification schemes. Then there is the fact that only temporary carbon credits, for which demand is very weak, can be issued for the carbon sequestered by Jatropha trees. This is because they only have a life span of forty years, after which the trees decompose and the carbon stored in them is released into the atmosphere again. Yet another contributing factor is the uncertain future of the CDM framework, which acts as a deterrent to risk-averse investors.

As this section has hopefully served to highlight, Jatropha projects can generate reductions in greenhouse gas emissions under certain conditions, in which case they can sell carbon credits. However, the high cost of obtaining certification coupled with low carbon credit prices cast serious doubts on the prospects for linking Jatropha projects to carbon financing. The good news is that carbon financing has turned out to be integral to the economic viability of the Jatropha projects, which have reached the point where they produce and sell carbon credits, suggesting that such projects should have no problems in meeting the additionality criterion.

HEALTH ISSUES

Most issues around Jatropha are similar to those of other crops and have been covered in previous chapters. One cross-cutting issue that we think deserves special attention is the fact that Jatropha is a poisonous plant.

In this chapter we look into the knowledge about the poisonous substances in Jatropha, the danger they pose, and precautions required in the cultivation and handling of Jatropha.

Photo 17: Euphorbia tirucalli hedges are commonly used around home compounds in Africa. Dombe, Mozambique (© Flemming Nielsen)

Jatropha is potentially lethal when ingested. This has caused some concerns and we have met people who are convinced that cultivating poisonous plants introduce a new and unprecedented risk to farmers.

However, Jatropha has a long history as a medicinal plant. Ingestion causes instant vomiting and is the reason for the common name 'purging nut'.

Many plants in nature are more poisonous than Jatropha and several are widely used as medicine, insect repellent, fencing and ornamentals.

In this context, it is clear that Jatropha cultivation does not introduce a new and unprecedented risk. Still, any poisonous plant poses some risk. In the case of Jatropha seeds processed locally and consumed in products like soap and lamp oil, it is important to understand the risks involved and take appropriate precautions.

Poisonous substances in Jatropha

Many toxic substances have been identified in Jatropha, including at least 65 diterpenes (Baldini, Raranciuc, and Vischi 2012, 3). Among the latter is a group of phorbol esters which is considered the most toxic compound in Jatropha. Six different phorbol esters have been identified in *Jatropha curcas* (Haas, Sterk, and Mittelbach 2002 cited in Devappa, Makkar, and Becker 2010, 481).

Because phorbol ester is by far the most toxic compound it is generally the only compound that is considered a health risk. Makkar and Becker found the following phorbol ester concentrations in *Jatropha curcas*: 2–6 mg/g dry matter were present in kernels, leaves (1.83–2.75), stems (0.78–0.99), flowers (1.39–1.83), buds (1.18–2.10), roots (0.55), bark (outer brown skin) (0.39), bark (inner green skin) (3.08) and wood (0.09), but not in latex (Basha et al. 2009).

Phorbol esters are considered co-carcinogens: they do not cause tumours but they promote the growth of tumours caused by other carcinogenic substances (Goel et al. 2007 cited in Devappa, Makkar, and Becker 2010, 482).

Other compounds in Jatropha have shown irritant, cytotoxic, anti-inflammatory, anti-tumour (Lin et al. 2003), molluscicidal, insecticidal, and fungicidal activities (Devappa, Makkar, and Becker 2010, 479).

Accidental Ingestion of Jatropha

All parts of Jatropha plants have traditionally been used for human and livestock medicine.

Ingesting Jatropha results in vomiting, diarrhoea within 15 minutes, followed by abdominal pain, and a burning sensation in the throat. Several studies have been published of particular children submitted to hospitals after eating Jatropha (e.g. Rai and Parul 2008).They have all recovered in 6-12 hours after symptomatic treatment only.

Roasting Jatropha seeds removes most anti-nutrients; however, phorbol esters remain even after 30 minutes at 160° C (Baldini, Raranciuc, and Vischi 2012, 4).

Accidental ingestion can also result from sharing equipment for processing of both food and Jatropha. For instance an expeller may be used for producing Jatropha oil and cooking oil. Extreme care must be taken to ensure no Jatropha residues are left in the equipment before beginning to process cooking oil. We have observed a large-scale farmer using an expeller in this way. The cooking oil was tested at a laboratory and no traces of Jatropha were found. Nonetheless, it is advisable to avoid sharing equipment for Jatropha and food processing.

Health Risks in Jatropha Cultivation

Many websites state that Jatropha is a skin irritant, implying that this is a problem when cultivating it. We are only aware of one peer-reviewed paper mentioning this. However, the paper is mostly an opinion piece with no original research, several inaccuracies and no information about the source of the information (Gressel 2008).
We have not experienced skin irritation ourselves nor have farmers mentioned it to us.

Phorbol ester appears to be able to cause skin irritation upon direct contact (Baldini, Raranciuc, and Vischi 2012, 4). During manual pruning, contact with the latex is unavoidable. However, as mentioned in the section "Poisonous substances in Jatropha", the latex does not contain phorbol ester, so if skin irritations do occur they must have other causes.

Health Risks in Jatropha Processing

During oil extraction with motorised expellers, the generated heat results in oil fumes which can cause nausea. Oil-processing facilities should therefore always be well ventilated.

The phorbol ester concentration in Jatropha oil is high and may cause skin irritation. Tests by Prasad et al. (2012) found that the concentration of phorbol esters in the oil is almost four times higher than in the press cake. Despite this, the Diligent company (which has extensive experience with processing) found that in general oil contact has no effect except in a few sensitive individuals (Diligent 2009).

Phorbol Ester in Jatropha Products

Fuel for Engines

Jatropha oil has a relatively high concentration of phorbol ester whereas biodiesel produced from the oil contained no phorbol esters (Prasad et al. 2012).

De-gumming, de-acidification, bleaching and deodorisation of Jatropha oil only reduces the phorbol ester content by 50% (Baldini, Raranciuc, and Vischi 2012, 5).

A review found that in adapted diesel engines, the use of plant oil as fuel generally results in a reduction of both regulated and non-regulated pollutants (with the possible exception of NOx) (Janssen 2009). Since most of the studies used other plant oils than Jatropha, there is some uncertainty about the applicability for Jatropha.

Nithiyanantham et al. (2012) remark that most studies of engine performance and emissions fail to use standard methodology, making it difficult to compare results.

Oil for Lamps and Cooking

Indoor air pollution causes about 3.5 million premature deaths globally every year and is therefore a serious health risk (Lim et al. 2012). Improved access to modern cooking fuels can avert 0.6 to 1.8 million premature deaths annually (Pachauri et al. 2013).

Jatropha oil lamps emit less PAHs[22] (240 times), CO_2 (3 times) and soot (1.5 times) than standard paraffin. However the production of NOx (5 times), CO (2 times) and hydrocarbons (7 times) is higher than standard paraffin. In particular, a special wick developed by Oomen Consultancy improves the combustion (Hamoen et al. 2011).

Jatropha and tobacco briquettes have been found to emit more PAHs (23–67 times), hydrocarbons (2 times), NOx (3–5 times) and soot (4–13 times) than the Malawi charcoal reference (Hamoen et al. 2011).

How these figures translate into the health risk of Jatropha compared to other fuels used for cooking and lamp oil is uncertain at this time.

Fertiliser

When press cake is used for biogas production, the phorbol esters are completely broken down within a few days (Joshi, Mathur, and Khare 2011).

However, if press cake is applied directly, phorbol esters enter the soil and will affect the soil fauna. INIA in Peru has reported that beneficial earth worms were killed by press cake applied directly to the soil (Prakash 2012). Laboratory tests of Jatropha oil mixed with black soil and clay found that when exposed to sunlight, phorbol ester was non-detectable within six days. In darkness there was little degradation of phorbol ester (Yunping et al. 2012).

In field studies of crops fertilised with Jatropha press cake, no traces of phorbol esters have been found. Crops that have been tested include sweet potatoes, Chinese kale and tomato (Kaewcharoensombat, Prommetta, and Srinophakun 2011, 218). In the field trials, the soils were also tested and no traces of phorbol esters were found.

Devappe found that phorbol ester degraded in the soil in six to nine days depending on moisture and temperature (Devappa, Makkar, and Becker 2010, 498).

Soap

Laboratory tests in Germany found that Jatropha soap is safe to use (Tatjana Vollner 2011). The main hazard is in the production process where caustic soda is used.
There have been reports from the field of Jatropha soap "burning" the skin (Mubonderi 2012). This is however not a particular Jatropha problem but is caused by either the wrong quantities of oil and caustic soda being used, or that the soap has not been allowed to cure. Soap should never be used right away but left to cure so the chemical reactions can finish. This usually happens within 48 hours.

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22 Polycyclic aromatic hydrocarbons

CONCLUSION

Several years after the collapse of the Jatropha hype, there are areas where smallholders continue to cultivate Jatropha. In some cases the cultivation is expanding. This supports the conclusion of this publication: namely, that there is a niche for Jatropha for local development, a niche where the services provided by Jatropha make it attractive compared to the alternatives.

The experience and current knowledge indicate that at present only areas with the following characteristics are promising for Jatropha for local development:

- The right agro-climatic conditions. This seems obvious but has been ignored in many cases in the past, leading to slow growth, pest problems and low yields.
- Low labour costs. Jatropha is currently harvested manually and under smallholder conditions this is likely to remain so in the future. The amount of seeds that can be harvested per day is relatively low and the daily income therefore so low that it is only attractive in areas with low labour costs.
- Low land costs. Jatropha gives a relatively low return per hectare and is therefore only competitive where land costs are low.
- High prices of imported goods. Jatropha can substitute for a number of imported goods and services. It is therefore at an advantage where imported goods are expensive.
- Seasonal fit with the cropping systems. From the above criteria it can be seen that Jatropha has the biggest potential in remote areas with extensive agriculture. Agriculture in these areas is mainly labour-constrained. If Jatropha can be tended at times of the year when little labour is required for other crops, it can improve the welfare of the farmers.
- Intercropping with food crops during the first few years is a solution to the low income from Jatropha during these years.
- Multiple products. Too much of the Jatropha production has been focused on one product only, namely oil to substitute fossil diesel. However, through diversification of products and services the value can often be doubled.

Most of the areas where all these criteria are fulfilled are located in Africa, in particular in remote areas of countries that only cultivate a fraction of their arable land. In most of Latin America, Jatropha is not attractive compared to other options due to higher labour costs. In much of Asia the land pressure is too high and the marginal areas that are available are not suitable for Jatropha cultivation. This could change when mineral diesel prices rise beyond a certain point and high costs are offset with higher product value.

For people who envisioned Jatropha as a silver bullet it may sound disappointing. However, from a development perspective it is great because there are so few options available for exactly these conditions; most crops, improved agricultural techniques and other development options require better agro-climatic conditions, more capital, access to modern energy services, better access to external inputs, access to external markets and a higher skill level.

Jatropha cultivation is all the opposite: Jatropha survives drought, bush fires and other hardships better than most other crops; it require minimal management; it can be cultivated without external inputs if the press cake is returned to the fields; it does not require an external market because all Jatropha-based products and services are in local demand. Instead of creating dependency on fragile supply channels and external markets, it can increase resilience and self-sufficiency.

Jatropha processing is a more ambiguous story. Local processing can be done with a hand press that requires little in terms of capital and skills, but also has limited development potential and is only suitable in relatively rare circumstances. Where Jatropha really shines as a tool of local development is when it can provide access to electricity and power machinery like water pumps and maize mills. This requires at least a powered mechanical press. It also requires skilled press operators and farmers who consistently adhere to good practices including harvesting only mature seeds, drying seeds sufficiently and quickly, storing seeds correctly, etc.

There are still technical challenges. However, they are not fundamental but rather a matter of optimisation to achieve more efficient and cheaper production. In practice the main obstacles have turned out to be organisational, i.e. how to reach and maintain the sufficient skill level and adherence to good practise throughout the chain. The areas where Jatropha for local development is most promising are also the areas with the poorest infrastructure, lowest educational levels and least experience in following rigid procedures and norms.

One work-around that is currently working in the field is to have a large-scale central processing plant processing seeds from thousands of smallholders. It can be located at a less isolated place where more skilled labour, infrastructure and services are available and, due to the low number of technicians required, good salaries can be paid.

However, many of the benefits of local production disappear with this setup. It becomes difficult and expensive to return the press cake to the fields; low quality oil for soap production is not available locally, etc. Jatropha tends to become just another cash crop – which is not bad but still limited compared to what it can provide.

Low Jatropha yield has been the main explanation provided for most of the failed Jatropha projects. Higher yield is therefore the logical solution. However, manual harvesting of Jatropha seeds is in the range of 40-60 kg/day no matter how high the yield per plant or per hectare is. Mechanical harvesting is experimental and unlikely to ever become an option for remote poor areas. In other words there are rather rigid limits on the daily income farmers earn from Jatropha and high yields are not going to change that.

Mechanised de-hullers provides the most efficient and quick way to raise farmers income from Jatropha because manual de-hulling takes about as long as the harvesting itself. Several different types of de-hullers have been tested in the field and their efficiency and costs are well known.

Larger seeds are one thing that can have a big impact on farmer's productivity and they appears to be relatively easy, quick and cheap to achieve through targeted selection. Regardless, we don't expect any big changes in this area over the coming five years. Since the collapse of the Jatropha hype only private companies undertake breeding on a significant scale. They target large-scale plantations which have other priorities such as uniform ripening and high per hectare yield.

Farmers, cooperatives and other small players have limited access to seed accessions for testing and selection, and in practice most just plant whatever seeds are available. No seed bank or seed exchange network currently exist. Establishing such services could be a very cost-efficient way of supporting Jatropha cultivators.

Much uncertainty remains about the exact yield of Jatropha and what determines yield levels. However, it is certain that in all areas, a very big yield gap has been observed between farmer's fields and trial plots. In most cases it comes down to a lack of information dissemination. The majority of farmers who have started Jatropha cultivation have not had access to sufficient extension services. Many have believed exaggerated claims and planted seeds in the most infertile and dry spots on their farms, and not bothered with weeding, pruning and other management practices. In other words, just as with processing, the main obstacle has in practice been organisational. In most cases yield can easily be doubled.

There is much to learn about how to optimise Jatropha cultivation. The hundreds of thousands of farmers who planted Jatropha during the hype were like a huge laboratory: endless combinations of planting methods, planting distance, intercrops, pruning regimes, pest management methods etc. were tried but there were few attempts to capture this experience. As a result little has been learned from farmers' experience. A farming systems research approach would have been useful but Jatropha was perceived as a ready solution that just needed to be rolled out – whereas the reality is that it is still highly experimental.

The Jatropha planted during the recent hype is only now approaching maturity. As a result relatively little oil has been produced and product diversification has not received enough attention. In addition to PPO or biodiesel, much value can be gained from biogas produced from the press cake, soap produced from low-quality oil, bio-pesticides, floor wax and other products. In most cases the value of the Jatropha seeds can be doubled through diversification.

The technical issues in Jatropha oil extraction are well understood. However, more experience is needed in order to determine how best to organise oil extraction to achieve the right balance of extraction efficiency, cost efficiency, oil quality etc. One promising option that has not been tested is mobile presses. Pressing locally means that only the oil needs to be transported. The seed cake can be used on the spot in biogas digesters and the resulting slurry in the fields, thus closing the nutrient loop.

Experience and economic analysis show that for local Jatropha value chains, PPO is a better option than biodiesel. It is easier and cheaper to produce but requires engine modifications. Due to the limited market for PPO engines and the diversity of diesel engines found in most rural areas, standard kits are not currently available. Each diesel engine requires custom modification which adds to both complexity and costs.

This points to an important issue with Jatropha: biofuels are often described as drop-in replacements but that is not completely true. As mentioned already, PPO requires light engine modifications; biodiesel requires replacement of rubber hoses in some engines; Jatropha for cooking requires special stoves and Jatropha oil for light requires special lamps. This makes the establishment of local value chains more complex and involved than many appreciated during the Jatropha hype.

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APPENDIX A: YIELD CURVES

Yield Curve by Trabucco et al. 2010

Source: Trabucco, Antonio, Wouter M. J. Achten, Colm Bowe, et al. 2010 Global Mapping of Jatropha Curcas Yield Based on Response of Fitness to Present and Future Climate. GCB Bioenergy 2(3): 139–151.

The authors use two data series to calculate a construct yield curves using a Chapman–Richards model. In the article the equation is provided: $\mathbf{Y=a(1-e^{-b*X})^c}$

It is stated that the first yield curve is from Foidl et al. (1996) and the second one is from their own observations. Since the latter has not been published the authors were contacted and Antonio Trabucco kindly shared a spreadsheet they used for the calculations.

The authors published the following parameters for the S-curve from the two data series:

	Nicaragua	Allahabad, India	Average
Max yield (a)	Not provided	Not provided	Not provided
b	0.793	0.91	0.8515
Shape (c)	3.344	3.588	3.466

Table 8: Parameters for Chapman–Richards model calculated by Trabucco et al. (2010)2010

From the spreadsheet that the authors kindly shared it can be seen that the following data points are used:

Year	Nicaragua (kg/ha)		Allahabad, India (kg/ha)	
1	250	assumed	200	assumed
2	450	measured	400	measured
3			1200	measured
4	850	measured	2000	measured
5	850	measured	2000	measured
6	850	measured	2000	measured

Table 9: Data points used by Trabucco et al. (2010) for yield curve model.

The data points from Nicaragua differ from the source (Foidl et al. 1996), where it is stated that:
"In 1995 an area of 1000 ha was grown with Jatropha curcas …"(Foidl et al. 1996, 77)

On page 79 Foidl et al. gives the following yield data:

Year	Methyl esters	Oil	Oil cake
1996	476	507	1069
1997	569	607	1280
1998	712	759	1600
1999-2018	712	759	1600

Table 10: Expected amounts of products for the years 1996-2018 (kd/ha) (Foidl et al. 1996, 89)

On the same page as the above table Foidl et al. write: *"The data of the first 3 years are derived from field trials, the following years are calculated on the basis of data from single adult plants. "(Foidl et al. 1996, 89)*

Our reading of the data by Foidl et al. is that none of the yield data are actually measured, i.e. the data in the table starts in year 1996, which is the same year the paper was published. That is why Foidl et al. write "expected amounts" in the caption to the table cited above.

How they have scaled the trial data to "expected yield" is not stated but we assume they have multiplied the trial data with the same constant every year to account for differences in management level, soil fertility etc. between the field trials and farmers' fields. If this is true then the shape of the yield curve is correct for the first three years.

The expected yield data for the years 1999 to 2018 are based on single plant observations and are therefore so uncertain that they cannot be used for extrapolating yield or to construct yield curves. For instance P. K. Ghosh measured yield over four years of 19 individual Jatropha plants and found that it varied between 0 and 850 g per plant (Reinhardt et al. 2008). This variation fits with our own observations too.

With only three reliable data points showing increasing yields every year it is not possible to assess when maturity and maximum yield occurs, and hence the Chapman–Richards model cannot be used.

However, to be able to use the Chapman–Richards model, Trabucco et al. opted to include the 1999 to 2018 data, i.e. accepting the expectation by Foidl et al. that maturity and maximum yield is reached in the fourth year.
There are discrepancies between the spreadsheet used by Trabucco et al. and our reading of the paper by Foidl et al.:
In Table 9 on page 64, seed yield is the sum of the oil and oil cake (press cake). Below we have compared the absolute and relative seed yield with the data used by Trabucco et al.:

Year	Trabucco et al. 2010		Foidl et al. 1996	
	Kg/ha	fraction	Kg/ha	fraction
1	250	29%		
2	450	53%	1576	67%
3			1887	80%
4	850	100%	2359	100%
5	850	100%	2359	100%
6	850	100%	2359	100%

According to the article by Trabucco et al., the expected yield around Managua where Foidl et al. sampled Jatropha is in the range 3501-5000 kg of dry seeds ha-1 yr-1. If these figures are used instead of the lower figures by Foidl, the yield in year three is 38-54% instead of 80% of maximum yield. This illustrates well that a yield curve based on just three known points tells a lot about the assumptions behind the missing data points but not much about what is happening in the field.

The other data series used by Trabucco et al. contains enough data points to make a reliable estimate of the growth curve. The reliability therefore depends on the quality of the data. The data is obviously not direct measurements since they are all nice round figures. However, this does not in itself disqualify the data.

With the information currently available to us we conclude that one of the two yield curves by Trabucco et al. must be discarded. The verdict is still out on the other curve as we don't currently have enough information to assess the quality of the underlying data.

Yield Curve by Nielsen F 2009

Nielsen F (Nielsen 2009) also used the Richards curve to fit a data series. In this case it a sufficiently long data series from Paraguay (Matsuno et al. 1985) is used.

The equation is: $Y=A+\frac{(C-A)}{(1+T\,e^{-B(x-M)})^{1/T}}$

Parameter	Value	Description
x		Year
A	0	Lower asymptote
C	3947	Upper asymptote, i.e. Max. Yield
M	6.9	Time to maximum growth
B	4	Growth rate
T	7	Near which symptote maximum growth

When the curve was created in the field in Mozambique, the original source of the Paraguay data was not available and instead they were read from the paper by Achten et al. (2008). To our knowledge the data was first cited in 1996 (Heller 1996). The original paper is in Japanese and is difficult to access. It may therefore have received little scrutiny by some of the authors citing it.

The yield data provided by Matsuno et al. (1985):

Year	kg/ha	Range
1	?	?
2	?	?
3	100	50-300
4	700	500-1000
5	1000	700-1500
6	2000	1000-3000
7	3000	2000-5000
8	4000	3000-6000
9	4000	3000-6000

Table 11: "Yield of Physic nut in Paraguay (Matsuno et al. 1985, 164)"

Notice that the "typical yields" in the second column are not simply the average or median of the range in the third column. Still, the nice round figures indicate that they are not direct field measurements.

We have recently obtained a copy of the original article and are currently having it translated. We are therefore not yet able to assess the quality of the data.

Yield Curve by Ab van Peer

Ab van Peer has proposed an almost linear yield curve based on a collection of data points from the literature, his own observations and information from various practitioners. S ee the main chapter for details.

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