Jatropha curcas in Oahu and Mozambique

Acknowledging scientific differences and resulting questions

Lindsey Marshall
Preface

This Master’s thesis is Lindsey Marshall’s degree project in Geography at the Department of Physical Geography and Quaternary Geology, Stockholm University. The Master’s thesis comprises 60 HECs (two terms of full-time studies).

Supervisor has been Lars-Ove Westerberg at the Department of Physical Geography and Quaternary Geology, Stockholm University. Examiner has been Peter Schlyter, at the Department of Physical Geography and Quaternary Geology, Stockholm University.

The author is responsible for the contents of this thesis.

Stockholm, 26 October 2010

Clas Hättestrand
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Abstract

In the current search for alternatives to fossil energy sources, scientists have expanded their biofuel research pools to include non-traditional crops. Plants that were once only thought of as food crops (for example rapeseed, maize, sugarcane, and sugar beet) are now experimented with and used for biofuel supply. Other plants that did not have any agricultural or commercial use are now integral parts of biofuel research and advancement. One of these plants, *Jatropha curcas*, has spread through the biofuel communities throughout the world. *Jatropha curcas* is noted for its high quality oil and ability to grow in poor conditions. Most of the interest in this tree is concentrated in the tropics, where a year-round growing/harvest season is possible.

This study was conducted in order to view and discuss *Jatropha curcas* in two different settings: two test fields at the Hawaiian Agricultural Research Centers on Oahu, Hawaii, and Sun Biofuels plantation in Chimoio, Mozambique.

After visiting Oahu, it was clear that, although some significant steps in pruning techniques had been achieved, many of the questions surrounding jatropha remained unanswered. These questions included, but were not limited to: What is the ideal irrigation level? Is the plant close to domestication? How can optimal yield be achieved? Are there ways to avoid dormancy? Additionally, as a result of the research, many new questions regarding environmental, social, agricultural, and economic aspects of jatropha arose.

In Chimoio, it became immediately apparent that the plantation was little more than a huge test plot at its current stage in August, 2009. There was no infrastructure being set-up or built either at Sun Biofuels or in the surrounding cities to accommodate for machine harvesting, crushing, pressing, storage, and transportation, even though the first harvest was scheduled for 2010. Additionally, there were no on-site engineers or scientists to help with the initial phases of growth and harvest.

It was evident that jatropha was growing on good quality soil in both Hawaii and Mozambique, and jatropha crops were planted on previous agricultural land. Just because it was shown that jatropha could grow on poor quality land does not mean that it actually grows there in a plantation-like environment. Additionally, because it was been proven that jatropha can grow on good quality soil does not mean it is a competitive substitute for other biofuel crops.

It is clear that jatropha has highly irregular qualities (for example, growth, seed content, oil content, oil properties) not just in different parts of the world or even in different plantations, but from genetically identical trees in the same plantation with the same growing conditions. This is an explanation for why jatropha data is so inconsistent across the world. Further scientific and engineering research must be put into jatropha before a company should embark on a large-scale plantation venture.
Sammanfattning


Denna studie genomfördes för att undersöka och diskutera *Jatropha curcas* i två olika miljöer: på The Hawaiian Agricultural Research Center, Oahu, Hawaii samt på Sun Biofuels Plantation, Chimoio, Mozambique.


Relevant data som har samlats in från de två besökta områdena, samt undersökta litteratur, presenteras i resultaten. Det är tydligt att jatropha har mycket varierande egenskaper med avseende på till exempel tillväxt, frönsättning, oljehalt samt oljans egenskaper; inte bara mellan olika delar av världen eller ens mellan olika planteringar, utan också från genetiskt identiska träd i samma plantering med samma odlingsförhållanden. Detta är en förklaring till varför data om jatropha från studier över hela världen är så inkonsekventa.

De frågor som uppkom från både Oahu och Chimoio tas upp i diskussionen. Det är uppenbart att ytterligare vetenskaplig och teknisk forskning måste investeras i jatropha innan ett företag kan tänkas ta sig an en storskalig produktion. Det är uppenbart att de två undersökta plantagerna saknar såväl god vetenskaplig kunskap om jatropha som utrustning för dess hantering.
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I would like to express my gratitude to my research advisor, Lars Ove-Westerberg. He initially suggested that I study jatropha, and has supported me fully and spent countless hours pouring over my notes, emails, and drafts. I am very grateful for all the time he has put into my paper, and to help guide and shape my research.

Dr. Richard Ogoshi and Dr. Mike Poteet of the Hawaiian Agricultural Research Institute on Oahu, Hawaii also deserve great thanks and recognition. They were kind enough to let me tour the facilities and access many parts of the jatropha papers and publications they had dedicated their research towards. Additionally, the strong knowledge in specific agricultural areas they shared with me was truly invaluable.

Nico Strydom of SunBiofuels, Chimoio, was kind enough to help me arrange my visit to the SunBiofuels plantation in Chimoio, Mozambique, and he left me in the good care of Ribero Manashe. Mr. Manashe, the crop manager at the plantation, spent many hours going over the finest details of the plantation, and his knowledge of jatropha and Mozambique helped me immensely.

Lastly, I would like to thank Peter Schlyter for helping me with the direction of my paper, and supporting me in practical matters.
Introduction

Throughout the world, crops are grown for the purpose of biofuel production. These biofuels, in the past thought of as temporary replacements for fossil fuels, are now becoming integral players on world markets.

Biofuel is mostly seen as a greener alternative to petro diesel and gasoline because it is made from plant or meat-based material, can have an almost limitless supply of inputs, and the marketing image of petro diesel alternatives tends to conjure up ideas of eco-friendliness (this is because biofuel crops are, for example, corn and soybeans which are familiar and edible crops). However, similar to petro diesel, biofuel also retains a portion of critics. Recently, in 2007, rising food prices sparked anger towards biofuels when news outlets disclosed that the reason for the price increase was that crops originally intended for food production were being used for biofuel production instead (Vidal, 2007). Because of the multifaceted use of maize and soybeans in the food industry and their role as leading contenders in the biofuel revolution (University of Minnesota, 2006), much of the biofuel backlash focused on removing food-crops as fuel crops (Kleiner, 2007).

The push for alternative biofuel crops has driven the scientific and agricultural communities of the world to explore less competitive, and often non-edible, crops. One of the first non-edible crops was the oil palm; however, this tree gained controversy when some outlets declared it an “environmental nightmare”, in that the management techniques have involved clearing of rain forest (Rosenthal, 2007). Agricultural communities have recently turned to the species *Jatropha curcas* (referred to in this document as *jatropha*), a perennial tree from the Euphorbiaceae family, as a candidate for biofuel production (Krypton Organic and Biofuel, 2009). This tree, native to Central America, has received interest from companies mainly because it is suited to growing in poor soil, is resistant to drought and insects, and can yield a high amount of good quality oil from its seeds (REUK, 2008).

There is plenty of vague and general information about jatropha and its use as a biofuel—this information does not always come from reliable sources and many conflicting accounts of the tree and its biofuel exist. Little information exists on cultivation methods, agricultural economic models, and the environmental and social impacts. Jatropha is touted as the "next big thing", but neither socio-economic nor environmental effects from large-scale production on plantations are thoroughly explored, mostly because biofuel crops plantations, and particularly the use of jatropha in this way, are extremely new. Furthermore, the current availability of land that can be used for both food crop and jatropha production sets the stage for potential conflicts when the interests of the biofuel industry clash with agricultural expansion schemes. In Hawaii, researchers are studying cultivation methods, genetic advances, and crop modelling. In Mozambique, as a result of a drastic expansion of jatropha production over the past 5 years, environmental, economic, and social impacts are just now surfacing.

Many questions have arisen since jatropha is relatively new to the biofuel market. Can jatropha be competitive with other biofuel crops? Will genetic modifications or selective breeding increase yield? Is it possible for the crop to be economically viable when grown in harsh conditions? Are there environmental concerns with jatropha's toxicity? Is it really a miracle crop?

As there are many unanswered questions regarding this biofuel crop, the aim of this research is to discuss jatropha as a biofuel crop in Mozambique and Hawaii, two places that are establishing themselves as jatropha investment areas, and identify general environmental, economic, and social points to be considered regarding jatropha plantations.
Plant-based liquid biofuels have been studied for over 100 years, but only recently have they played a larger role in producer and consumer interest. Various reasons exist as to why biofuel did not gain popularity early on. The most common reason is that oil was simply a better substitute. In 1853, E. Duffy and J. Patrick used a crude conversion process to transform peanut oil into the first documented biofuel (Biodiesel Times, 2005). This experiment, as well as following ones by Roudolf Diesel and the Otto Company, were not influential enough to promote and expand biofuel use, and thus diesel engines were modified to run on readily available petro diesel (Nothegh, 2001). During the 1920s and 1930s, there were sporadic accounts of biofuel experiments throughout the world; however, it was not until 1977 that industrial processes for biofuel production were invented and patented by Expedito Parente (of Brazil) (Parente, undated). Over the next 30 years, countries across the world began trials of transesterifying various plant-derived oils.

Plant-based liquid biofuels fall into two categories: bioethanol and biodiesel. The fuel outcome is entirely dependent on the crop. Bioethanol requires a crop high in sugar (for example sugar cane or maize). The crop is subjected to a yeast fermentation, which in turn yields ethanol (Pu et al., 2007). Ethanol can be blended with gasoline, or can be used alone as a gasoline substitute.

Biodiesel requires plants that contain high amounts of oil (for example rapeseed or soybean). The oil is extracted from the plant, most commonly by a pressing and filtering process. This oil is called pure plant oil, or PPO. PPO can, in some cases, be used to run in a diesel engine without any oil processing. On average, PPO has a kinematic viscosity one order of magnitude higher than petro diesel fuel (Nothegh, 2001). This is because vegetable oil contains chains of hydrocarbons bound together by glycerol (called triglycerides). The hydrocarbon chains of vegetable oil have a similar structure to petro diesel. But, the attached triglycerides are harmful for a diesel engine, and assist in reducing engine performance. PPO (when run through a modern, non-modified diesel engine) leaves oil deposits throughout the engine, chokes injectors, clogs combustion chambers, and congests valves (Nothegh, 2001). In addition, PPO has poor atomization properties. This means that when the oil is forced through a diesel engine's fuel injector nozzle, it does not break into a fine mist when it enters the combustion chamber. Rather, larger particles remain and weigh the oil down. This results in low combustion chamber performance, and leads to less effective acceleration performance, or non-ignition.

To improve the engine performance of PPO, the viscosity must be reduced. Three of the most studied viscosity-reduction processes include transesterification, microemulsification, and dilution with petro diesel (Nothegh, 2001). Transesterification consists of reacting PPO with an alcohol (usually methanol because it is an inexpensive alcohol and generally cheaper than all its other counterparts) to neutralize the free fatty acids. A catalyst is used at the same time which results in the removal of the triglycerides and creation of an alcohol ester (Figure 1 and Figure 2).

After the transesterification process concludes, the glycerine sinks to the bottom and the liquid left on top is the biodiesel. The biodiesel can be separated from the glycerine, and the glycerine can be put to use (for example, as an input for soap production). There are different transesterification methods that people subscribe to depending on the fatty acid profile of the PPO; these methods vary depending on the solvent type and amount, for example if an acid or base is used in the process, how much heat is applied, and how much oil is to be converted.

Blending is a process that can only happen after transesterification. With the blending method, pure biodiesel (transesterified PPO or animal fats, or both) is blended with petro diesel. Splash blending is a common procedure where a certain amount of biodiesel is poured into petro diesel and stirred together to create a specific percentage blend. Pure biodiesel (often called B100) is commonly blended into mixtures of 5 percent (B5) to 20 percent (B20). At some temperatures biodiesel is immiscible in blends. However, even though the triglycerides are removed, low-level blends can still retain a higher viscosity than petro diesel. This can lead to separate layers of biodiesel and petro diesel in fuel tanks. A study by the Woods Hole Oceanographic Institute found
that many blends claiming to be B20 had blending levels that varied from 10-74% (due to the layering of biodiesel and petro diesel) (Woods Hole Oceanographic Institute, 27 02 2008).

Microemulsification is a process that happens after blending. This process has been used to combat layering of biofuel and petro diesel, and to extend the shelf life of blended biodiesel. Microemulsification is normally used to blend oil-based and water-based liquids until the immiscible particles can no longer be detected. This process creates a true blend of biodiesel and petro diesel. Pure biodiesel degrades quicker than pure petro diesel, as discovered in a study by the University of Idaho. Over a period of 28 days, biodiesel was shown to degrade 5 times quicker than petroleum diesel (Peterson and Möller, undated). By using a microemulsification process, the degradation process could be slowed or minimized and thus enhance the quality and extend the shelf life of the fuel.

The world production of biodiesel started to drastically expand around the beginning of the 2000s. Between 2002 and 2006, there was an average world biofuel growth rate of 40%. The total world production in 2006 was estimated at 5.5 million tons. Approximately 80% of this amount was processed in Europe, and >20% was processed in the United States. In 2007, the processing in Europe surpassed total world production for 2006. It was estimated at 5.7 million tons (Collins, 2006). Despite these increasing numbers, biodiesel only accounts for approximately 5% of total world production of vegetable oil. To get a better picture, in 2005, 110 million tons of vegetable oil were produced worldwide; the majority of this amount consisted of soybean and palm oil (Collins, 2006).
The growing biofuel market, and the 2007 backlash against food crops for biofuel has led to searches for new biofuel crops that can compete with existing crops, grow on arable land not currently in agricultural use, or grow on land ill suited for normal biofuel or food crops. Jatropha has recently been explored for its potential as a biofuel crop due to its high oil content and ability to grow in a variety of agricultural conditions. Jatropha is a tree that originates in Central America (Figure 3), and it was spread throughout the word by the Spanish and Portuguese slave and trade ships. Eventually the tree found permanent homes in India, Asia, and Africa, and more the United States.

Figure 3. A world map indicating where jatropha is located throughout the world (dated 2006). Notice that jatropha is concentrated in tropical and subtropical regions in the northern and southern hemisphere. (Henning, 2006)

Jatropha's migration in the context of this research

During the early 1900's many Asians decided to migrate east. With a few of these immigrants, jatropha plants or seeds followed, and eventually landed on the islands of Hawaii. Hawaii is one of the few places in the United States where jatropha grows wild. It remained relatively unnoticed until an initiative by the Hawaiian government, which called for the exploration of biofuels, including sugarcane, maize, and jatropha. Currently, it is grown at two research centers (operated by HARC-the Hawaiian Agricultural Research Center) on the island of Oahu; one located near Pearl City on the South-West part of the island, and one located near Waimea on the North-Central part of the island. These two locations cater to research for large, United-based companies that have biofuel crops growing throughout the world.

Jatropha was introduced to Mozambique in a similar manner to that of Hawaii. It most likely travelled by slave ships that came from Central America. Around 1800, slave ships began arriving from Brazil, a likely country where jatropha travelled from (Crawfurd, 2009) because of its close proximity to jatropha's origin, Central America. This story has been confirmed by various actors in the agricultural community (Manashe, 2009). The tree is recognized by locals throughout Mozambique as a shade tree, and less as a hedge tree as it is commonly referred to by documents, articles, and publications. It is rarely seen acting as a hedge tree, possibly because land is government-owned in Mozambique and hedges between properties are either not necessary or are built for more study material, especially in the case where farm animals are involved.

It is not until the last 5 years that jatropha has shifted in use from a shade tree to an agricultural crop in both Hawaii and Mozambique. Dozens of companies, almost all foreign, have taken advantage of the Mozambique government's interest in promoting and expanding biofuels, and more recently, the government passed a national biofuel policy to promote and expand jatropha investment.

This relatively new biofuel crop is a good research candidate, owing to its unique ability to grow in poor soil conditions and that it has (in the last 3-5 years) been so heavily promoted by the media as a "miracle crop".
Methodology

4.1 Motivation for research trips

I selected two different locations for field research: Oahu, Hawaii, and Chimoio, Mozambique.

Hawaii

The Hawaiian Agricultural Research Center (HARC) is a private 501c5 non-profit organization. A 501c5 non-profit organization promotes the interest of people engaged in agricultural activities, such as raising livestock, harvesting crops, cultivating plants, and so on. In addition to this, a 501c5 must adhere to the following principles:

- The betterment of the conditions of those engaged in agriculture
- The improvement of their products
- Their occupational efficiency

Recently, HARC was asked by the government of Hawaii to explore the possibilities of biofuels in Hawaii, both from agricultural and economic positions. This request was raised because the Hawaiian Electric Company was interested in exploring clean energy sources. On October 20, 2008, the State of Hawaii and the electric companies in Hawaii signed an agreement stating that by the year 2030, the state would supply 40 percent of all electrical needs and 70 percent of overall energy needs with clean energy sources (Hawaiian Electric Company, 2009).

Before the request was placed, HARC had already experimented with maize and sugarcane. Jatropha was suggested, as other research stations in Hawaii were experimenting with it. A search for a suitable variety ensued, and jatropha was found growing at the botanical garden in Pearl City. Some cuttings and seeds were harvested, and this local species was planted at both HARC locations on Oahu. Jatropha was one of the plants to be studied as a biofuel candidate for the State of Hawaii, along with maize and sugarcane. Relatively little research was taking place locally on the Hawaiian Islands outside of the HARC research stations. To complement and enhance the research in Oahu, HARC scientists Mike Poteet and Richard Ogoshi, along with other jatropha researchers, took a trip around the world in 2007 to visit jatropha plantations and researchers in Europe, America, Africa, and India. For full details of the report refer to (Poteet, 2008).

- No existing economic model of a jatropha plantation exists, and much research and development is needed before this model can exist.
- Jatropha does not display uniformity, and this is a major impediment to agricultural economics.

HARC is carrying out research to address the bullet points above, to create a future for jatropha in Hawaii and possibly other parts of the United States. At HARC South, Dr. Mike Poteet has devoted his jatropha work to production and industrial agriculture. This HARC station gravitates towards technical development of crops and tends to choose crops for study that are easily commercialized (existing examples include sugar cane and coffee).

Mozambique

There are many international companies that have invested in jatropha plantations in Mozambique in the last 6 years. See Table 1 for investment information.
Table 1. Table showing recent jatropha investors in Mozambique. (Government of Mozambique, 2008)

<table>
<thead>
<tr>
<th>Company Name</th>
<th>Investment Amount (in USD)</th>
<th>Year</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petromoc (Mozambique)</td>
<td>$408 million</td>
<td>2007</td>
<td>45,000 ha</td>
</tr>
<tr>
<td>Sun Biofuels (UK)</td>
<td>No information</td>
<td>2005</td>
<td>No information</td>
</tr>
<tr>
<td>Deulco (South Africa)</td>
<td>No information</td>
<td>2004</td>
<td>No information</td>
</tr>
<tr>
<td>Energem (Canada)</td>
<td>$55 million</td>
<td>2007</td>
<td>65,000 ha</td>
</tr>
<tr>
<td>Odeveze (Canada)</td>
<td>$150 million</td>
<td>2008</td>
<td>70,000 ha</td>
</tr>
<tr>
<td>Viridesco Limited (UK)</td>
<td>No information</td>
<td>2005</td>
<td>200 ha</td>
</tr>
<tr>
<td>D1 (UK)</td>
<td>No information</td>
<td>2007</td>
<td>&gt;20,000 ha</td>
</tr>
</tbody>
</table>

In 2006, Sun Biofuels acquired a 5,000 hectare plantation from Alliance One, a US tobacco company. The plantation, located in Chimoio (west-central Mozambique), was absent of tobacco, and land was covered with weeds, shrubs, and trees. Sun Biofuels spent two years preparing the land for jatropha, clearing and tilling the land, and 18 months restoring the infrastructure. Before Sun Biofuels acquired the land, it was pre-cut with dirt roads forming different sized and shaped compounds.

The Sun Biofuels jatropha plantation project is supported and financed by EEA Fund Management of London, which has over US $1.7 billion of assets under management (All Africa Global Media, 2009). At the plantation in Chimoio, there are over 500 people employed from the surrounding communities (Manashe, 2009) and slightly over 200 permanent, full-time workers (Manashe, 2009). Migrant laborers are common in Mozambique.

4.2 Procedures for data collection

Data collection for this paper consisted of personal interviews, tours of jatropha plantations and research centers, and a literature review of recent biofuel publications from researchers in the USA, Germany, UK, India, and Mozambique.

My initial trip, in March 2009, was to the Hawaiian Agricultural Research Center (HARC), where agricultural economic issues regarding jatropha production are being addressed, and some of the most advanced field research is carried out. In order to collect data relevant to agricultural and scientific advances and issues, I relied heavily on previously carried out experiments and the resulting data from four areas: jatropha domestication, yield, micropropagation, and crop automation. Understanding that not all relevant information is documented, I conducted several interviews and toured two HARC facilities (HARC North, near Waimea, and HARC South, near Pearl City). The interviews were carried out in person, by email, and by phone. To ensure the data collection was accurate and thorough, all in-person interviews were summarized using quotes and key words. The interview topics ranged from jatropha cultivation, advances in agro technology, application of jatropha in Hawaii, and the impacts of large companies on local communities, to other relevant topics. Each interview was customized according to the interviewees' specialization, studies, prior knowledge, and past and current work and research areas. The tours of HARC were documented with digital photographs, digital recordings, and notes. I was also given literature on jatropha from researchers which helped answer both broader questions about jatropha in general, and specific questions about research advancements in Hawaii.

My second trip took place in August 2009 to Mozambique. I took multiple tours of the Sun Biofuels plantation in Chimoio where over 900 hectares are planted with jatropha. This gave me a chance to observe the work environment, see how the company worked with and interacted with the local community, and speak with supervisors and managers. I also had time to see the city of Chimoio, and discovered what agricultural ventures and multinational companies are also competing for land, which led to a general overview of life and society in that city. Additionally, I explored the potential of Mozambique to be a key exporter of jatropha to the European Union. Many companies already established in Mozambique plan to take this direction.
4.3 Procedures for data analysis

After I completed the trip, I assessed the data I collected both in Mozambique and Hawaii, and combined it with information gathered by other researchers and professionals regarding biofuels in developing countries.

The data analysis took place during a period of 8 months in Stockholm, Sweden. I first processed the literature that I found of jatropha, biofuel businesses in Mozambique, and current agricultural trends, and related topics. This provided me with sufficient background to properly conduct research in Hawaii and Mozambique.

After I completed the literature review, I formulated my interview questions based on the data that I collected about my interview subjects, and their areas of expertise. This process varied, depending on the knowledge of the researchers and professionals compared to mine, and lead to additional data procedure collections. The interview information I gathered from Hawaii was the basis for my trip to Mozambique.

4.4 Limitations

In Mozambique, almost all of the non-managers spoke Portuguese. This provided difficulties when conducting field interviews with workers at Sun Biofuels and locals in Chimoio. It was also discovered in Mozambique that there is no real market existing for jatropha. Most plantations are still in experimental stages. Although there are a few plantations that are crushing and producing jatropha oil and soap, the large-scale operations are still in infancy. Many models previously examined before the data collection (out grower models, for example) were not used because of the absent market.
Results

5.1 Climate conditions

Jatropha is accustomed to a variety of climate conditions. Cultivated and wild jatropha grows almost exclusively in tropical and subtropical regions (between 0 and 40 degrees latitude on both hemispheres). It grows at altitudes of 0-1000 meters and in areas where the mean annual temperature meets or exceeds 25° Celsius. Researchers at SG Biofuels in San Diego, California have found multiple strains of jatropha that can grow and flower in colder conditions (temperatures lower than 15.5° C) and at higher elevations (1600-1800 m above sea level) than what is normally expected (Lane, 2009).

Generally accepted levels of rainfall run from 200mm to 1200mm per year, although 500-800mm per year is desirable as higher yield per hectare has been recorded with these rainfall levels (Poteet, 2009), (Manashe, 2009). Jatropha can withstand extended drought periods because it stops flowering and fruiting, goes dormant, and retains high quantities of water in its branches. During this period, the tree experiences water stress; the effect the dormancy period has on future fruit and oil production has not been thoroughly studied. In continuously wet tropic regions, jatropha can flower and fruit year round. In drier tropic conditions, jatropha can go dormant when drought conditions persist for months. However, jatropha tends to produce higher oil yields in drier tropic conditions compared to wetter ones (Jones and Miller, 1992, p.7).

Native environmental conditions

Jatropha is native to Central America. It is accustomed to a tropical climate that has periods of both wet and dry seasons. Note that it is known that jatropha is native to Central America, but it is not known exactly where. Thus, the native climatic conditions are generalizations of this region.

Soil

In Central America, the most common soil groups are acrisols, nitisols, lixisols, cambisols, leptosols, and andosols. The most common soils are described in Table 2. Jatropha is suited to grow in all of these types of soils. In general, many types of soils are suitable for jatropha. It easily adapts to agriculturally-poor soils (for example low fertility sites and alkaline soils), and is known to grow in areas in Central America that are exceptionally rocky, nutrient poor, highly sodic, and excessively draining. The only conditions unsuitable for jatropha are wetlands and areas susceptible to ground frost, as this can kill the tree (Poteet, 2009) (Figure 4).

Table 2. Common Central American soils that jatropha grows in. Jatropha is native to Central America (Driessen, 2001).

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrisols</td>
<td>Soils that are characterized by accumulation of low activity clays in an agric subsurface horizon and by a low base saturation.</td>
</tr>
<tr>
<td>Nitisols</td>
<td>Accommodate deep, well drained, red, tropical soils with diffuse horizon boundaries and a subsurface horizon with more than 30 percent clay and moderate angular blocky structure elements that easily fall apart into characteristics shiny, nutty elements. Strongly weathered soils but more productive than other red tropical soils.</td>
</tr>
<tr>
<td>Lixisols</td>
<td>Have an agric horizon (subsurface horizon with a distinct higher clay content than overlying horizon).</td>
</tr>
<tr>
<td>Cambisols</td>
<td>Soils having either a cambic horizon (a horizon showing evidence of alteration with respect to the underlying material), or a mollic horizon overlying a subsoil, which has a base saturation of less than 50 percent in some part within 100 cm from the soil surface.</td>
</tr>
<tr>
<td>Leptosols</td>
<td>Soils which are EITHER limited in depth by continuous hard rock within 25 cm</td>
</tr>
</tbody>
</table>
Jatropha curcas in Oahu and Mozambique—acknowledging scientific differences and resulting questions

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andosols</td>
<td>Soils with a vitric or andic horizon (slightly to moderately weathered horizons in pyroclastic deposits dominated by short-range-order minerals, notably allophane and imogolite) starting within 25 cm from the soil surface.</td>
</tr>
</tbody>
</table>

Jatropha can easily grow on land where slopes exceed 18% and has been used to combat erosion in excessively sloped areas (Poteet, 2009). Figure 5 outlines the region that jatropha is native to, and shows the extent of sloping in that area.

Rainfall

Jatropha can withstand various rainfall levels, as well as areas that are susceptible to prolonged drought periods. In Central America, rainfall averages between 1200-4000mm per year. This is higher than the averages for regions where jatropha is currently cultivated as a biofuel. Jatropha can thrive in high rainfall areas as long as the soil is well draining and the area is not a wetland. Figure 6 shows average annual rainfall for the region that jatropha is native to.
Hawaiian environmental conditions

In Hawaii, jatropha is grown at two HARC research stations: one located slightly northwest of Kapolei, and one located towards the north of the island close to Waimea.

Soil

The HARC research centers had two types of soil that jatropha grew in: Molokai Ap1 and Molokai Ap2 (Table 3). These are both oxisols (ferralsols according to the FAO classification). This soil was well suited for jatropha, as well as other biofuel crops such as sugar cane and maize. Figure 7 outlines the distribution of oxisols on Oahu.
Table 3. This table describes the characteristics of the two soil types jatropha grows in on the island of Oahu, Hawaii (USDA, 2000).

<table>
<thead>
<tr>
<th>Name</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molokai Ap1</td>
<td>Dark red-brown (2-5 YR ¾) silty clay loam, weak very fine, fine and medium granular structure; slightly hard, friable, slightly sticky and plastic; many roots; many interstitial pores; many very fine black concretions that effervesce with hydrogen peroxide; strong effervescence with hydrogen peroxide; extremely acid (pH 4.4); clear wavy boundary</td>
</tr>
<tr>
<td>Molokai Ap2</td>
<td>A dark reddish brown (2.5YR 3/4) silty clay loam, dark red (2.5R 3/6) dry; weak medium and coarse subangular blocky structure parting to moderate fine and very fine granular; slightly hard, friable, sticky and plastic; common roots; common very fine tubular and interstitial pores; common fine black concretions; violent effervescence with hydrogen peroxide; very strongly acid (pH 4.6); clear smooth boundary</td>
</tr>
</tbody>
</table>

Figure 7. Soil map for the island of Oahu (Hawaii). Note the concentration of oxisols that runs north-south on the island. Agriculture on the island is heavy in this area (Hue et al., 2006).

Altitude

Jatropha in Hawaii was cultivated at altitudes of 0-300m. Most plantations were slightly sloped (1-3%) (see Figure 8)
Figure 8. Altitude map of Oahu (Hawaii). Note that most of the island is relatively close to sea level (0-1000) meters. This is where jatropha grows (HIGP, undated).

**Rainfall**

HARC South receives approximately 500-750mm and HARC North receives 750-1500mm of rainfall per year, respectively (Poteet, 2009) (Ogoshi, 2009). Irrigation is used at both stations to supplement rainfall. Jatropha produces a higher yield when less irrigation is used. In a trial using 18 month old trees, the trees that received 125 liters per 30 meters per hour (or 300mm of irrigation per year) produced twice the berry yield than the trees that received 250 liters per 30 meters per hour (or 600mm of irrigation per year). This irrigation is in addition to the 50-150 mm per year of rainfall (Poteet, 2009).

**Mozambique climate conditions**

Mozambique sits on the south east coast of Africa, surrounded by Swaziland, South Africa, Zimbabwe, Zambia, Malawi, and Tanzania (Figure 9). The Zambezi River (one of 5 major rivers in the country) divides Mozambique into two regions; the land north of the river consists of hills, plateaus, and rugged highland, and the land south of the river is made up of broad lowlands which develop into mountains in the southernmost region of the country (BBC, 2009).
Soil

At the Sun Biofuels plantation in Chimoio, soils run the gamut from clay based to sand based (Manashe, 2009). Jatropha is planted in all of the different soil types, and the trees have similar characteristics (described later in this chapter).

Rainfall

Mozambique has a tropical climate with two seasons, a wet season from October to March and a dry season from April to September. Local climatic conditions vary depending on altitude. Mozambique's annual precipitation averages 769 mm per year; the driest months (July and August) receive 13 mm per month, and the wettest (January) receives 130 mm over a course of 9 days (ClimateTemp, 2009).

5.2 Tree overview

Sowing

The sowing process is strictly dependent on the rainfall during the sowing to germination period when no artificial irrigation is used. Jatropha is hand sown into a cultivated soil bed. To emerge, the crop needs to receive ca. 40-50 mm of rainfall over a period of two weeks (Manashe, 2009). The base temperature should be around 25°C Celsius (Manashe, 2009). At plantations where no irrigation is used, sowing can be achieved during the beginning of the rainy season. For example, in Mozambique sowing takes place in October—the beginning of the rainy season that lasts until March (Manashe, 2009). On average, there is 1,200 to 1,300 mm of rain during this period so essentially sowing could be achieved during any two week interval of this period (Manashe, 2009). Many seeds have a soil ring around them to capture additional moisture, as water capture is critical during the initial growing period (Figure 10). This ring is usually observed on sloped land to capture water that would otherwise runoff and be lost.
Depending on the area, soil types can vary across single plantations. Therefore, planting methods are adapted to the particular soil and slope. Plants that grow in sandy soil will be elevated slightly (1/3 to ½ meter above row height) so the roots can drive down into the ground to capture additional moisture (Manashe, 2009).

**Germination**

When the seed germinates, the shell splits and the radicula extends along with 4 lateral (peripheral) roots and one tap root (Poteet, 2009). The roots are generally c. 8 to 10 cm in diameter (Poteet, 2009). In soils with poor water-retention rates, a tap root is necessary to keep the plant properly hydrated and to avoid dormancy. Jatropha tap roots can extend 2 meters underground in poorly hydrated soils; otherwise they grow to a depth of 1 meter (Poteet, 2009). If cuttings are planted instead of seeds, the rainfall requirements (or irrigation requirements) during the initial phase are reduced slightly. Cuttings develop without a tap root, and only have lateral peripheral roots (Poteet, 2009) (Manashe, 2009).

**Pollination, seeds, fruiting, and flowering**

Jatropha is both monoecious and protandrous, meaning that it cross-pollinates as well as self-pollinates (Solomon, 2002). The first flowing and fruiting take place between 4 months and two years (Poteet, 2009), but these fruits are either pruned off or drop off naturally. Flowering starts at the bottom of the tree, and moves upwards (Figure 11). The flowers form in clusters, and these flowers fruit in uniform. Both male and female flowers appear on the same clusters (Figure 12). At the HARC stations, researchers had heard from sources in India that the female flowers open first (Poteet, 2009). Field observations confirmed that the ratio of male to female flowers is highly skewed; there tend to be many more male than female flowers on each cluster. Per cluster, there is a 9:1 ratio of male flowers to female flowers (Poteet, 2009).

On the other hand, a report by Solomon Raju and Ezradanam (2002) concludes that male flowers open first, and that male flowers are produced daily until the male buds are exhausted. The female flowers begin to open 2-6 days after the first male flowers.
The process from flower to fruit takes 2 weeks, and the process of fruit to maturity takes 6 weeks (Poteet, 2009). If temperatures are optimal, continuous flowering occurs for thirty to forty days (Poteet, 2009). Fruiting takes place during the rainy season, although year-round fruiting can occur with irrigation (Ogoshi, 2009). Berries start off as green, then change to yellow, and finally, when they are mature, they are a dark brown (see Figure 13 and Figure 14). Jatropha seeds are produced in triovulate fruits that are toxic to humans and animals due to the toxalbumin – toxic protein curcin as well as several other phorbol esters that have toxic elements (Poteet, 2009). Yellow berries can be harvested, but their oil content is lower than mature brown berries (Poteet, 2009). The process of sowing to (full) harvest for jatropha can take upwards of 2 years (Ogoshi, 2009). It is possible to harvest low amounts of fruit during the first year. In contrast, the soybean process takes 80-120 days and rapeseed takes 74-140 days.

Branches, trunks and leaves

Jatropha branches and trunks contain latex, making them extremely flexible (Figure 15). When the branches are split, the latex drips out from the wound at a fairly high rate (Figure 16). The latex is traditionally used as a blood clotting agent (Poteet, 2009). Undiluted latex can speed up the blood
clotting process in humans. When the latex is diluted to a certain level, the blood clotting process can take longer than if the blood was left to clot naturally.

Leaves are arranged individually on the stems, not clustered together, and have a palmate venation structure and are attached to the stem by petiole, making them suitable for high levels of radiation capture (Figure 17). The internodes can extend from 5-7cm.

According to Duke (1983), leaves contain:

- b-sitosterol – reduces blood levels of cholesterol
- stigmasterol – used as a dietary supplement
- campesterol – used as a dietary supplement

Young jatropha leaves can be eaten, and common practice is to steam or stew them (Duke, 1983). Leaf properties are important because jatropha sheds its leaves when temperatures fall below a certain point. The leaves can either be re-absorbed into the soil, or removed to become compost or waste.

**Biomass**

The ratio of tree mass above ground to below ground is 2.5:1 (Poteet, 2009). An average tree has 70% moisture, mostly because of the high levels of latex found inside the tree (Poteet, 2009). The carbon content of an average tree was measured at 40-42% on a dry basis (Poteet, 2009). This amounts to 3 tons of carbon (excluding fruit) per 1000 trees.
**Maturity**

It takes three to five years for the trees to reach their maximum height of 5 meters (Poteet, 2009). During the first year, tree height varies from 1/3 meter to 1 meter (Poteet, 2009) (Figure 18). Canopy shape and size of younglings varies from one main trunk with little branching, to multiple branching and more developed canopies. After three years, trees planted in fields tend to resemble each other, including trees absent of pruning, training, or other tree-manipulating strategies (Poteet, 2009).

Most trees develop with multiple low branches (Figure 19). It is possible to induce the branching, especially low-branching, by aggressive pruning during the first two years (Poteet, 2009). This is practiced at plantations that use hand-harvesting methods, because multiple low branching can lead to higher berry yield (Figure 20).

For mechanized harvests, low branches are removed during the first year, and trees are shaped to have one main trunk that can be grasped by a harvesting machine.

**Fatty acid composition**

The fatty acid composition of jatropha seeds is outlined in Table 4. The percentage of the fatty acids varies greatly, especially the 18-Carbon chain fatty acids. The variability provides difficulties during the transesterification process (Ogoshi, 2009).
Table 4. The fatty acid profile of *Jatropha curcas* seeds. These numbers are important factors in the transesterification process, where the fatty acids are broken down to produce biodiesel (Poteet, 2008; Lele, 2007).

<table>
<thead>
<tr>
<th>Fatty acid profile</th>
<th>% of total (Poteet)</th>
<th>Range % (Poteet)</th>
<th>Content % (m/m) (Lele)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myristic acid (C14)</td>
<td>1.4</td>
<td>0.5-1.4</td>
<td>0.38</td>
</tr>
<tr>
<td>Palmitic acid (C16)</td>
<td>15.6</td>
<td>12.0-17.0</td>
<td>16.0 max</td>
</tr>
<tr>
<td>Palmitoleic acid</td>
<td></td>
<td>1-3.5</td>
<td></td>
</tr>
<tr>
<td>Stearic acid (C18)</td>
<td>9.7</td>
<td>5.0-9.7</td>
<td>6-7.0</td>
</tr>
<tr>
<td>Oleic acid (C18:1)</td>
<td>41.0</td>
<td>37.0-63.0</td>
<td>42-43.5</td>
</tr>
<tr>
<td>Linoleic acid (C18:2)</td>
<td>32.1</td>
<td>19.0-41.0</td>
<td>33-34.4</td>
</tr>
<tr>
<td>Linolenic acid</td>
<td>&gt;0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arachidic acid</td>
<td>0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gadoleic acid</td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other materials</td>
<td>4.0</td>
<td>4.0-8.4</td>
<td></td>
</tr>
</tbody>
</table>

5.3 **Planting methods**

**Spacing**

Density and row spacing depend on the type of harvesting method. For hand harvesting, extremely dense spacing is used to maximize berry growth per hectare. Too-dense spacing has been shown to lead to dormancy, especially when radiation capture is minimized because of excessive canopy cover (Ogoshi, 2009). For machine harvest, a spacing of 2mx3m or 1.5mx4m provides enough width between rows to accommodate harvesting equipment, as well as farming equipment such as trucks and tractors. Shows the density of jatropha plants per hectare with various spacing methods. Table 5 shows the density of jatropha planted per hectare with various spacing methods. Jatropha is commonly planted in hedge-row styles, and denser and less dense versions are seen throughout the world (Figure 21 and 22).

Table 5. Typical spacing patters on jatropha. The second column totals how many trees per hectare can be planted with this spacing pattern. This table assumes the planting area is a square hectare (Marshall, 2009).

<table>
<thead>
<tr>
<th>Spacing</th>
<th>Trees/Hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td>1mx1m</td>
<td>10000</td>
</tr>
<tr>
<td>2mx1m</td>
<td>5000</td>
</tr>
<tr>
<td>2mx2m</td>
<td>2500</td>
</tr>
<tr>
<td>2mx3m</td>
<td>1666</td>
</tr>
<tr>
<td>3mx3m</td>
<td>1111</td>
</tr>
<tr>
<td>3mx4m</td>
<td>833</td>
</tr>
</tbody>
</table>

*Figure 21. A dense test plot with 1x2m spacing at HARC North (Marshall, 2009).*

*Figure 22. A widely spaced test plot with 2x3m spacing at HARC South (Marshall, 2009).*
Seeds production and oil content

Seed production ranges from c. 0.4 tons per hectare per year to over 12 t./ha./a., for mature trees (Jones and Miller, 1992), and an average tree produces 6-7kg seeds per year (Poteet, 2009). In Mali, where jatropha is planted in hedges, the reported productivity is from 0.8 kg. – 1.0 kg. of seed per meter of live fence (Henning, 1996). This is equivalent to between 2.5t./ha. and 3.5t./ha. Whole jatropha seeds contain on average 22-42% oil content, although with poor growing conditions the oil content can be as low as 15% (Poteet, 2009). Green berries on average have 10% less oil content than ripe berries (Poteet, 2009). The kernel produces 60-67% oil (Poteet, 2009). Mechanical extraction of just the kernels is not recommended due to the kernel’s softness and tendency to jam the pressing equipment, and the additional oil that would be lost from the other parts of the seed. See Table 6 to Table 10.

Table 6. The low ranges and high ranges of seeds per hectare (assuming tree density is 1,000 to 1,666 trees per hectare) (Poteet, 2009)(Manashe, 2009).

<table>
<thead>
<tr>
<th>Low range</th>
<th>High range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4 tons of seeds/ha</td>
<td>12 tons of seeds/ha</td>
</tr>
<tr>
<td>2.5 tons of seeds/ha</td>
<td>3.5 tons of seeds/ha</td>
</tr>
<tr>
<td>1.5 tons of seeds/ha</td>
<td>5 tons of seeds/ha</td>
</tr>
</tbody>
</table>

Table 7. The low range and high range of oil content per seed (Poteet, 2009)(Manashe, 2009).

<table>
<thead>
<tr>
<th>Low range</th>
<th>High range</th>
</tr>
</thead>
<tbody>
<tr>
<td>15% oil content/seed</td>
<td>42% oil content/seed</td>
</tr>
</tbody>
</table>

Table 8. The low range and high range of oil content per kernel (Poteet, 2009)(Manashe, 2009).

<table>
<thead>
<tr>
<th>Low range</th>
<th>High range</th>
</tr>
</thead>
<tbody>
<tr>
<td>60% oil content/kernel</td>
<td>67% oil content/kernel</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Metric ton of oil/ha</th>
<th>Liters/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4 tons seeds @ 15% oil content</td>
<td>0.06</td>
</tr>
<tr>
<td>0.4 tons seeds @ 22% oil content</td>
<td>0.088</td>
</tr>
<tr>
<td>0.4 tons seeds @ 42% oil content</td>
<td>0.168</td>
</tr>
<tr>
<td>1.5 tons seeds @ 15% oil content</td>
<td>0.225</td>
</tr>
<tr>
<td>1.5 tons seeds @ 22% oil content</td>
<td>0.33</td>
</tr>
<tr>
<td>1.5 tons seeds @ 42% oil content</td>
<td>0.63</td>
</tr>
<tr>
<td>2.5 tons seeds @15% oil content</td>
<td>0.375</td>
</tr>
<tr>
<td>2.5 tons seeds @ 22% oil content</td>
<td>0.55</td>
</tr>
<tr>
<td>2.5 tons seeds @ 42% oil content</td>
<td>1.05</td>
</tr>
<tr>
<td>3.5 tons seeds @ 15% oil content</td>
<td>0.525</td>
</tr>
<tr>
<td>3.5 tons seeds @ 22% oil content</td>
<td>0.77</td>
</tr>
<tr>
<td>3.5 tons seeds @42% oil content</td>
<td>1.47</td>
</tr>
<tr>
<td>5 tons seeds @15% oil content</td>
<td>0.75</td>
</tr>
<tr>
<td>5 tons seeds @ 22% oil content</td>
<td>1.1</td>
</tr>
<tr>
<td>5 tons seeds @42% oil content</td>
<td>2.1</td>
</tr>
<tr>
<td>12 tons seeds @15% oil content</td>
<td>1.8</td>
</tr>
<tr>
<td>12 tons seeds @22% oil content</td>
<td>2.64</td>
</tr>
<tr>
<td>12 tons seeds @42% oil content</td>
<td>5.04</td>
</tr>
</tbody>
</table>
Table 10. The amount that one hectare of jatropha PPO can yield with a fixed price of $250 per litre (Poteet, 2009)(Manashe, 2009).

<table>
<thead>
<tr>
<th>Seed Content</th>
<th>Metric ton x $250</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4 tons @ 15%</td>
<td>15</td>
</tr>
<tr>
<td>0.4 tons @ 22%</td>
<td>22</td>
</tr>
<tr>
<td>0.4 tons @ 42%</td>
<td>42</td>
</tr>
<tr>
<td>1.5 tons @ 15%</td>
<td>56.25</td>
</tr>
<tr>
<td>1.5 tons @ 22%</td>
<td>82.5</td>
</tr>
<tr>
<td>1.5 tons @ 42%</td>
<td>157.5</td>
</tr>
<tr>
<td>2.5 tons @ 15%</td>
<td>93.75</td>
</tr>
<tr>
<td>2.5 tons @ 22%</td>
<td>137.5</td>
</tr>
<tr>
<td>2.5 tons @ 42%</td>
<td>262.5</td>
</tr>
<tr>
<td>3.5 tons @ 15%</td>
<td>131.25</td>
</tr>
<tr>
<td>3.5 tons @ 22%</td>
<td>192.5</td>
</tr>
<tr>
<td>3.5 tons @ 42%</td>
<td>367.5</td>
</tr>
<tr>
<td>5 tons @ 15%</td>
<td>187.5</td>
</tr>
<tr>
<td>5 tons @ 22%</td>
<td>275</td>
</tr>
<tr>
<td>5 tons @ 42%</td>
<td>577.5</td>
</tr>
<tr>
<td>12 tons @ 15%</td>
<td>450</td>
</tr>
<tr>
<td>12 tons @ 22%</td>
<td>660</td>
</tr>
<tr>
<td>12 tons @ 42%</td>
<td>1260</td>
</tr>
</tbody>
</table>

**Jatropha oil processing**

Jatropha oil processing is done in machines designed specifically to crush jatropha fruit, extract the oil from the fruit and kernel, and refine and filter the oil. Machines are commonly ordered from India (where a more established jatropha system exists) and range in size depending on how much material will be processed (Poteet, 2009). Below is an example of an Indian-made machine in Hawaii (Figures 23-29). This machine is fairly small and requires a manual transfer of material from part 1 to 2, and part 2 to 5. The machine could be modified so that the entire process is mechanized (Poteet, 2009).

**Figure 23.** Part 1: A jatropha crushing/pressing machine imported from India. Jatropha berries are placed in the pyramid-shaped top of the machine so that the shell and seed can be separated (Marshall, HARC South, 2009).

**Figure 24.** Part 2: A secondary crush. The seeds are fed into the top of the machine, and the oil and protein meal runs down the metal slide at the bottom (Marshall, HARC South, 2009).
5.4 Tree management

Weed and insect control

Jatropha is susceptible to primary pests, as well as secondary pests when pesticides are used. These pests vary depending on the region it is planted in. Post-emergent pesticides are most common, but
on occasion pre-emergent pesticides may be sprayed in an area to combat pests, for example the mealy worm (Figure 30). During the sowing phase, the mealy worm will eat germinating seeds (Manashe, 2009). This can happen in small to large patches on plantations, and sowing must be done again usually after a pesticide is applied to the area (Manashe, 2009).

![Image of mealy worm damage](image)

**Figure 30.** A field at Sun Biofuels in Chimoio, Mozambique, where extensive mealy worm damage during the sowing period took place (Marshall, Chimoio).

### Fertilization

Fertilization is not required for fruit production, but is commonly used on jatropha plantations throughout the world. In Hawaii, it was found that trees that were fertilized (amounts of N, P, and K unknown) produced a seed yield twice as high as trees that were not fertilized (Poteet, 2009). On poor quality soils, it has been show that small amounts of calcium, magnesium, and sulphur applied to the soil through fertilizer result in better yields (Jones and Miller, 1992, p.7). When soils are lacking in phosphate, mycorrhizal associations can assist in plant growth during the first five years (Jones and Miller, 1992, p.7).

Fertilization was used not only in Hawaii, but also in Mozambique. Because the trees in Mozambique had not produced seeds for a harvest, there was no information as to how the trees reacted to the fertilizer. See Table 11 for information about the ranges of N, P, K, and S observed in various trials in Hawaii and Mozambique.

**Table 11.** The range of nitrogen, phosphorous, potassium, and sulphur fertilization observed during this study. These ranges were applied on hectares containing 1,000 to 1,666 trees (Poteet, 2009)(Manashe, 2009).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>30 kg/ha</td>
<td>40 kg/ha</td>
<td>10 kg/ha</td>
<td>40 kg/ha</td>
</tr>
<tr>
<td>High</td>
<td>45 kg/ha</td>
<td>60 kg/ha</td>
<td>19 kg/ha</td>
<td>45 kg/ha</td>
</tr>
</tbody>
</table>

### Emissions

Unlike fossil fuels, biofuel crops absorb carbon dioxide throughout their lifetime. A jatropha tree absorbs around 8 kgs of CO₂ every year (Koundinya, 2008). At many plantations, approximately 2,500 trees are planted per hectare. This amount of trees multiplied by the absorption rate means that 20 tons of CO₂ is sequestered per year. This absorption rate can generally last for 40-50 years, the approximate lifetime of a jatropha tree (Plant Jatropha, 2008). Only approximations about absorption rates can be made however, because the calculations depend on many assumptions, including:

- Emissions from growing the feedstock (for example petrochemicals used in fertilizers)
- Emissions from transporting the feedstock to the factory
- Emissions from processing the feedstock into biodiesel
Other factors can be very significant but are sometimes not considered. These include (Mortimer et al., 2008):

- Emissions from the change in land use of the area where the fuel feedstock is grown
- Emissions from transportation of the biodiesel from the factory to its point of use
- The efficiency of the biodiesel compared with standard diesel
- The amount of CO₂ produced at the tail pipe
- The benefits due to the production of useful by-products, such as cattle feed or glycerine

**Greenhouse gas emissions from combustion**

The cetane number is often referred to when discussing pollution from cars and trucks. The cetane number measures the ignition delay of fuel, meaning the time between the start of injection and start of combustion in the engine (Midwest Biofuels, 1994). A higher cetane number means that there is a shorter delay between injection and combustion, resulting in improved engine performance and less emissions. A lower cetane rating means the opposite.

Biodiesels have higher cetane ratings than petrodiesel, and can reduce tailpipe emissions by up to 20% (Beer and Grant, 2006). The reason for this is that biodiesels contain less aromatic hydrocarbons, hydrocarbons that are part of the world’s overall emissions and pollution problem.

In a recent article Crutzen et al. (2007, p. 11197) have estimated that “…the global warming by N₂O [from rapeseed biodiesel] is on average about 1.0-1.7 times larger than the quasi-cooling effect due to ‘saved fossil CO₂’ emissions”. Compared to CO₂, N₂O has 298 times more impact on the ozone layer (over a 100 year period). To combat N₂O emissions, diesel engine cars and trucks have modified exhaust treatments. However, these modifications tend to be expensive and reduce fuel efficiency, and thus lead to increased CO₂ emissions (Engine Manufacturers Association, 2004).

5.6 **Jatropha industry infrastructure: Hawaii and Chimoio**

**Hawaii**

The HARC South station has three fields of jatropha. The fields were planted for the following purposes:

- Field 1: Crop spacing study, two varietal study.
- Field 2: Irrigation trial, two varietal study.
- Field 3: Pruning experimentation, multiple varietal study.

At the HARC North station, Dr. Richard Ogoshi is working on crop models and agricultural economics (also carbon sequestration). There is one field at this station which contains two test plots. The first test plot is approximately 3 years old. The first test plot was created for a pruning and density study. The second plot (at the time this paper was submitted) was approximately 1.5 years old. The second plot is designed for a spacing study, as well as a varietal study.

**Investors**

There are quite a few large American companies involved with jatropha. Baer Cropscience, Bayer CropScience, Daimler-Chrysler, and Archer-Daniels Midland Company are represented in Hawaii,
and all are planning to explore jatropha jointly in India before investing in jatropha in the United States (Bayer CropScience, 2008). Cargill has taken on a project for the Department of Defence that includes crushing, something that is vital for jatropha oil production. On Oahu there is one biodiesel processor that can handle a very low capacity. For jatropha studies to be expanded in Hawaii, a large crusher and high capacity biodiesel processor must be present to represent real-life situations.

Field trials at HARC South

Field 1

Field 1 is the initial test plot for varying spacing between jatropha trees. The field is divided in half, with trees from Indian seeds planted on the right, and trees from Madagascar seeds planted on the left. This plot tested widths of approximately 30, 60, 90, and 120 cm between trees in a row. The initial study found that 90 cm was the optimal distance. It was also noted on this field that trees that were fertilized produced a seed yield twice as high as trees that were not fertilized. No pesticides were used on this field, although some trees were subject to pests similar to mealy bug.

Field 2

Field 2 consists of trees 18 months old with 90 centimetre spacing between trees. At the early stages, the trees were heavily pruned to take on the shape of a single-trunk tree. A drip irrigation system is used, and this allows for various irrigation trials. The first trial used an irrigation rate of 250 litres per 30 meters per hour on the upper half of the field, and used half that irrigation rate on the lower half. This amounted to 60 cm of irrigation in one year for the upper half, and approximately 30 cm of irrigation per year for the lower half. In general, the lower half had twice the yield of the more heavily irrigated upper half. Note that there is no data on rain infiltration rates and surface runoff absorption rates for HARC, or for Hawaii in general, so with the irrigation trials many assumptions had to be made.

Field 3

Field 3 is a varietal test plot. In March 2009, all trees were ca. 1 year. Seeds for this field came from other islands in Hawaii, Central and South America, Africa, India, Asia, and Germany. Even though it was hard to distinguish varietals by sight, some plants showed similarities such as the seeds from Hawaii. These plants had extremely dense branching and leafing compared to other varietals. Researchers speculated that Hawaiian seeds may have been better adapted to the climatic conditions, compared to seeds that have never grown in Hawaii.

Chimoio

Overview and location

Jatropha plantations are concentrated in the middle of Mozambique, with most plantations running slightly south of Beira up to the border Malawi. Most plantations are dedicated to growing jatropha for biofuel; yet, the infrastructure for processing and refining oil does not exist yet. Mozambique has one refinery with a limited production capacity of 10 tons per day (Manashe, 2009). Other companies with established plantations in Mozambique plan to install their own pressing and refining equipment, although most of these companies are 1-2 years away from having a harvest sizeable enough to necessitate such machinery and equipment. Some growers have expressed interest in forming co-ops, or jointly purchasing equipment for crushing/pressing/refining (Manashe, 2009).

Size and set-up

In January 2009, during a non-continuous 22 day process, 880 hectares of jatropha were planted (Manashe, 2009), each hectare having approximately 1,667 trees (Manashe, 2009). An additional 100 hectares are presently (Aug 2009) being planted with jatropha and the company envisions
having over 15,000 hectares planted in Mozambique in the future. Additionally, this plantation has a test plot which uses 96 accessions of jatropha from Tanzania, Ethiopia, and Indonesia. The purpose is to test for oil content—should Sun Biofuels expand production in Mozambique or other African countries, they want to ensure the optimal plants are used. The first full harvest is scheduled for 2010, and optimum yield is estimated by the year 2012. See Figure 31 for an image of the plantation.

![Figure 31. A picture of the Sun Biofuels plantation in Chimoio, Mozambique (Marshall, Chimoio 2009).](image)

### Employees

Depending on where the plantation is situated, workers can be Mozambicans or from neighboring countries such as South Africa, Tanzania, and Zimbabwe (Manashe, 2009). Migrant workers can show up unannounced at company gates, but many times when extra labor is needed (for example during a harvest), the job advertisements will spread by word of mouth. In some cases, hundreds of workers can show up when only a few dozen are needed (Manashe, 2009). Most agricultural workers at Sun Biofuels are between the ages of 20-30, and most are men. Workers have the opportunity to advance into management positions, through the demonstration of specific skills. These opportunities are rare, but still allow for an increase in wages.

For permanent workers, meaning employees that work full time (40 hours/week year round); housing is provided by the company for no cost to the workers. It is not uncommon for many plantation workers to live on the plantation in shack-like housing. Mozambique has specific laws governing housing for plantation workers. If a housing structure is established on a plantation, then the workers have a right to live on the land indefinitely. The housing structure does not necessarily have to be for people who work on the plantation. For the housing structures intended for workers, the inhabitants by law can remain, even if they choose to work somewhere other than the plantation they reside on (Manashe, 2009). This case follows even if another company, foreign or domestic, assumes rights to the land. Often these households consist of families with children, and it is common that both parents work on the plantation. Also, housing and independent farming set-ups exist on plantations. The individual farms are used to produce goods to provide for the family, or to produce goods that would be sold at road-side markets. (Manashe, 2009).

Upper-management lives in individual houses, with access to filtered hot and cold water year round, and air conditioning is provided. Fresh, filtered water is provided around the clock for workers and residents. The water was located a few years from the housing structures, making it convenient to collect water at any point during the day. There was no cap on water collection.
Working conditions

A typical workweek is 40 hours split over 5 days. The labor is difficult and intense, and is not suited for children or aging adults. Works at the plantation flows over a 7 day work week, so work weeks are split among the workers so that an even amount of labor is available on the plantations all days. No traditional benefits such as healthcare, retirement, etc., are included with wages, but "benefits" can include named items such as free housing and access to water.

The workers are paid once a month, always in cash (unless they have a bank account, which is rare). This system poses many problems, mainly for the security of those in charge of collecting and distributing the cash. Mozambique's banking structure is relatively weak, stemming from the lack of use. Workers are paid in cash because they do not (in general) have bank accounts, even though banks may exist in relatively close proximity.

Oil consumption in Mozambique

The Mozambican total consumption per year of fossil fuels is 590,000 tons of oil. With a population of 20.5 million (Namburete, 2006), this equates to 28.7 kgs per person each year. The CIA World Fact Book estimates a consumption rate in Mozambique of 0.714 barrel/day per 1,000 people. To compare, the country with the highest consumption is the Virgin Islands, with an average of 845.382 barrels/day per 1,000 people (CIA World Factbook, 2008). The country averages 700,000m³ of oil consumption (Namburete, 2006). Diesel imports make up ca. 18% and petrol imports account for ca. 75% (Government of Mozambique, 2008). The average annual oil imports exceed US $270 million, roughly equivalent to 11% of Mozambique's GDP (Namburete, 2006). It is possible for local market to consume 100 thousand m³ even at higher blending levels of 15-20%, as proposed by PETROMOC (Government of Mozambique, 2008).

CO₂ emissions increase

The increase in jatropha plantations has brought an increase in the petro diesel usage. When a company assumes rights to a plantation, the farm land is usually left in a condition that requires extensive ploughing and use of diesel-burning farm equipment. Transforming a plantation into working quality can take upwards of 1 year, depending on the size, shape, and additional factors. Moreover, new equipment must be brought to the plantation. This is done by ordering equipment from South Africa, since Mozambique does not have a large array of advanced farming equipment.
6 Discussion

Depending on investor requirements, jatropha may or may not be a suitable biofuel crop. Along with a general lack of agricultural and economic data, there are various other issues with the crop jatropha. The following were identified during this study as areas that need to be addressed:

- Plant issues
- Government issues
- Social issues
- Local issues
- International issues
- Jatropha compared to competing crops

6.1 Plant issues

Jatropha berry yield and oil content yield can vary between plants with different or identical genetic make-up, and between plants growing in the same climate conditions. Varying yield has a direct impact on the economic situation of jatropha, because the yield amount is the basis for determining whether or not a plantation will be economically viable (profitable).

All of the trees in the 3 trials at the South HARC Station and 2 trials at the North HARC station showed irregularities, which included:

- Different sizes of same-aged plants from year 0-3: This means that yield can vary greatly when trees are not uniform in size.
- Different branching patterns in same aged plants: More branching means more berries, and less-branched trees are undesirable and indicate lower yield.
- Non-uniform fruiting on same tree: This can cause problems when harvesting, because harvesting will have to take place multiple times (leading to higher labor costs) and non-ripe berries could potentially be harvested.
- Varying oil content: If oil content is not the same in berries of the same size or even from the same tree, this means that the plantation is not producing at optimal levels, which ultimately leads to lower revenue.

Natural uniformity is not always evident within the first 12 months after sowing. Uniformity in tree shape was achieved to some degree with aggressive pruning (in Hawaii). Man-induced uniformity is generally attained during the early stages of tree maturity (3 years). Even with aggressive pruning it is not always guaranteed that trees will take on identical shapes. At HARC South, man-induced uniformity was only present in a few rows, and was not displayed in every single tree in the uniform rows. Identically (or very similarly) shaped trees are important for estimating yield, especially when plantations are very large. When uniformity cannot be achieved across a whole plantation, processes (such as harvesting) can become more difficult and costly, and optimal yield cannot be achieved, especially in the case where some trees are smaller than others.

In the United States, uniformity is necessary because harvests will be carried out by machines. The most likely machine to carry out jatropha harvests would be similar to nut harvesters. These machines drive down the middle of the rows and grab and shake the bottom of the tree. One thick trunk is necessary for this machine. If there are multiple low branches, the machine may not be
able to grab the branches, or the thinner low branches may break under the pressure of the harvester.

In India, Africa, and Asia, harvests are usually carried out by hand and uniformity does not weigh as heavily. In places where jatropha berries are hand-harvested, for example India and Africa, variability does not pose a problem because humans (unlike machine harvesters) are able to easily harvest in thick and varied growth, fixed and variable costs can be considerably less, and there is less competition in these marketplaces (Poteet, 2009).

When maximum output per acre is a necessity and uniformity to a certain degree is required for machine harvesting, it is unacceptable to have a field that contains high yielding trees and low yielding trees (Poteet, 2009). Because berries ripen at different paces on the same tree, it is possible that non-mature berries can be accidentally harvested and lead to lower output levels.

Irrigation can be a costly component when calculating inputs for jatropha plantations. At HARC, where multiple irrigation trials have taken place, it is still unknown what the ideal irrigation rate is for the specific growing conditions there. Some studies showed that less irrigation produced higher berry yields, and other studies showed the opposite. Moreover, it cannot be assumed that if an ideal irrigation rate is found in Hawaii (or even Oahu), it applies to anywhere else besides Hawaii.

Irrigation and yield uncertainties remain with jatropha because it is not domesticated. Plants are considered domesticated when they cannot grow and reproduce without the help of humans. In Asia, the Americas, and Africa, jatropha grows wild. These wild plants grow in the same fashion as jatropha grown on plantations, so much so that they are indistinguishable. Currently, jatropha is not domesticated. All other biofuel crops are domesticated in the broad sense, meaning that they adhere to the traits of domestication syndrome (see Table 12).

Although jatropha is not domesticated, there are different varieties that come from different parts of the world. What generally distinguishes one variety from another are specific characteristics (for example, low toxicity vs. high toxicity, leaf shape, etc.). Since jatropha must compete with other biofuel crops that are highly domesticated and genetically modified, genetic modification is ideal as it will speed up the process of traditional cross-breeding.

Table 12. The domestication traits for plants as outlined by Harlan (1992). These traits can be applied to 400 plant species, among which there are varying degrees of a wide range of domestication traits (Gepts, 2004). In general, tree and forage crops are considered to be only partially domesticated. Jatropha, if applied to this scale, would be considered non-domesticated.

<table>
<thead>
<tr>
<th>Trait selected</th>
<th>Selection stage</th>
<th>General</th>
<th>Specific trait</th>
<th>Crop examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seedling</td>
<td>Increase in seedling vigour</td>
<td>Loss of seed dormancy</td>
<td>Many crops</td>
<td></td>
</tr>
<tr>
<td>Reproductive system</td>
<td>Increased selfing rate</td>
<td>Adoption of vegetative propagation</td>
<td>Tomato, Cassava</td>
<td></td>
</tr>
<tr>
<td>Harvest or after harvest</td>
<td>Increase in seed yield</td>
<td>Loss of seed dispersal</td>
<td>Maize, Legumes, maize, Wheat, barley, maize, maize, amaranth</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>More compact growth habit</td>
<td>Legumes, rice</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase in the number or size of inflorescences</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase in the number of seeds per inflorescences</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Change in photoperiod sensitivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumer appeal</td>
<td>Color, size, taste, texture</td>
<td>Reduction in toxic substances</td>
<td>Many crops, Cassave, lima bean</td>
<td></td>
</tr>
</tbody>
</table>

Genetic modifications of jatropha tend to focus on:

- Removing seed toxicity
- Maximizing oil content of seeds
• Tree shape
• Ripening time of fruits on the same tree
• Equalizing the number of male and female flowers per cluster

It is not possible to domesticate a plant just by cross-breeding it. It is important to know the genetic diversity and traits both among and within natural populations of jatropha trees (Achten, 2010). Additionally, basic reproductive knowledge, mating patterns, pollinators, and quantitative genetic variation must be further explored (Achten 2010) before embarking on full scale domestication and genetic modification of jatropha. Additionally, plantations that use just one seed variety (such as the SunBiofuels plantation) run the risk of inbreeding, which can cause harm to the genetic properties of the seed for future crops.

6.2 **Government issues**

In 2006, the Government of Mozambique has set forth multiple studies to examine the potential of introducing biofuel programs. The aims were as follows:

• Reduce the import of liquid fuels
• Widen the access to energy sources
• Create job opportunities
• Diversification of community livelihood strategies hence being a vehicle for poverty reduction
• Create or share basic infrastructures, establishing important synergies and enabling otherwise scarce flows of investment into the agribusiness
• Create a set of valuable by-products like the co-generation of electricity, production of organic fertilizers and supply of human and animal feed proteins
• Value the enormous and dormant agro-climatic potential of the country
• make good use of the geostrategic location of the country and respective irrigation, harbour and petroleum infrastructures
• Make a significant contribution to the global effort for the mitigation of the environmental damages
• Be a part of the vast and ever-growing international biofuels market through its export; and increasing the overall production capacity of the country (Government of Mozambique, 2008)

Jatropha seems to be the main candidate for this program due to the recent investment in jatropha plantations by many international companies. However, a more diverse range of biofuel crops (described in the previous section) is starting to make headway in Mozambique as well.

Since the aims and efforts were introduced, hardly any material has been published on jatropha and many of the aims have not been accomplished or even started. There has been some investment in jatropha from foreign biofuel companies; however, many of these companies are essentially conducting test plots with little emphasis on the future. For example, at Sun Biofuels in Chimoio, it was uncertain how harvests would occur, where jatropha berries would be processed, and how the oil would be stored and transported. There were no existing oil storage facilities, no processing machines, and no transportation equipment anywhere close to the plantation.
For mechanized harvest, there currently is no machine specifically aimed at jatropha. It is possible that an existing machine, such as a nut harvester, could be adjusted for jatropha. This type of harvesting is preferred in some parts because mechanized harvest calls for less labor, provides greater efficiency, more area can be harvested in a shorter time period, and a better automated process will exist for the plantation.

Jatropha seeds can degrade quickly, especially in the tropical climate which it is accustomed to (Lele, 2008). Therefore, jatropha oil must be stored in specific containers that allow little to no air penetration, and these containers are costly. Storage (i.e. minimizing air and water contact) is very important after the oil is extracted, since it has a high acid concentration. The possibility of degradation runs high. It is preferable to store the oil in tanks covered with a nitrogen blanket.

6.3 Social issues

A major drawback to biofuel crops are the issues surrounding the food vs. fuel debate. At the heart of these issues is the ethical question of if it is better to plant food or non-food crops, and if it is right to plant non-food crops if not everyone has enough food. Many opponents of biofuels argue that people in Mozambique lack sufficient amounts of food, and the land would be better used for agricultural land for the locals. Some companies combat this by setting aside portions of the land to be food-producing areas (Manashe, 2009). The economic aspects that arise question what is best for the economy in local, country, and international terms, and if it is economically efficient to use degraded or poor quality land instead of high quality farm land.

Food vs. fuel is an ongoing debate that gained intensity in 2007 when rising food prices were attributed to the substitution of food crops for fuel crops, and the replacement of food crops by fuel crops. A World Bank paper attributed the 70-75% rise in grain prices (maize, wheat, rice) from 2005-2008 to biofuel production combined with other factors (Mitchell, 2008). Some parties think that the rise in food prices stemmed from the conversion of maize from a food crop to a fuel crop in many parts of the world. Companies began selling maize for biofuel when MTBE (a ground water pollutant) was banned from gasoline in 2006 in multiple states in the United States (Energy Information Administration, 2003), and maize was viewed as a cleaner energy alternative. Additionally, maize prices worldwide were relatively cheap, and demand for maize (for biofuel use) began to rise.

In many parts of the world, agricultural land is necessary for food crop production to sustain households, local and regional communities. Problems can arise when agricultural land for food crop production is substituted for biofuel crops. This concerns individuals and local communities, as well as agricultural-based export markets. The prospect of cultivating biofuel crops on land less suitable for agricultural is therefore encouraging. Because of jatropha's ability to grow in harsh conditions with little rainfall, it does not have to compete with land suited for food crop production. As more than 50% of Africa's land area provides suitable growing conditions for jatropha, the possibility of using land not previously used for agriculture and less suitable for food crop production has shed a favourable light on jatropha by the communities and groups who have argued against expansion of biofuel crops. A further positive trait is that jatropha has been suggested as a measure against soil erosion. As a result, the interest in jatropha has swept through biofuel investors, and plantations already have been established in many African countries (Manashe, 2009).

In theory, it is possible to plant jatropha in such areas, but that seems to not be the case. Degraded land does not create ideal growing conditions for jatropha; instead it just allows for the plants to grow, but not to full capacity. Degraded land is often times located far from roads, cities, and water making it difficult to set up a plantation, much less to find a work force to tend to and harvest the trees. This raises the following question: just because jatropha can grow in degraded land conditions, should it be grown there? Or even, will it be grown there? In many cases, jatropha (intended for biofuel production) is not grown on degraded land, but instead is grown on good-quality agricultural land. So, although jatropha has become synonymous with harsh conditions, this is not the reality. The reality is that jatropha is being grown on good quality agricultural land and former plantations, and in this way its “unique characteristics” are not being expanded upon.
Rather, if it continues down this path it will most likely be bred to grow in good conditions, and may lose its (genetic) ability to grow in harsher, more unforgiving conditions.

Another pressing social issue is how foreign businesses will affect the standard of living among Mozambicans, e.g. regarding economy and finances, housing, water, food, and education. In social terms, a company fares well when it improves the standards of people's lives, compared to what they were before the company came in. The agricultural sector contributes to approximately 80% of all jobs in Mozambique (Population Project, 2001). There is a minimum wage of 1,126 meticais per month (US $37.26) (All Africa Global Media, 2008), which is among the lowest minimum wages in Mozambique when compared with the industry and services sectors. This minimum wage, for one, would be sufficient to avoid poverty, but not everyone receives one pay check—rather, the head of house receives the pay check, while children, parents, and possibly relatives and spouses depend on this pay check as well.

Currently there is no legislature in Mozambique that requires any amount to be put into social programs (including education and health). It is unknown if any companies provide these services for their workers or the workers’ families. In Brazil, where there is a highly developed agricultural and ethanol sector, 1% of sugar cane prices (net) and 2% of ethanol prices (net) must be allocated to health and educational services for workers in the sugar cane industry (Smeets, 2006).

Education in Mozambique is essentially free from grades 0-12, but there are matriculation fees that deter many parents from sending their children to school (US Department of Labor, 2006). This type of education structure is relatively new, and not something the older generations were exposed to. Thus, many parents do not see the benefits of sending their children to school, and do not mind when their children would rather play with their friends than attend class. Between 1996 and 2003, the percent of children between ages 7-14 attending school averaged around 50% (US Department of Labor, 2006). The latest statistics (from 2007) show that over 1,000,000 Mozambican children under the age of 18 did not attend school in any capacity. These statistics also showed that most of these children lived in rural areas with very poor families (US Department of Labor, 2006). Unlike Brazil, where the biofuel industry contributes to education, the jatropha industry in Mozambique does not contribute to education in the same way. This could be attributed to the fact that the industry is still in its infancy.

6.4 Local issues

Mozambique is home to numerous jatropha plantations that are in various stages of operation. Since the government's push for jatropha investment and expansion, many international companies are experimenting with jatropha, and are trying to determine if jatropha is a viable commodity to pursue. Economically and financially, jatropha is unproven and unconfirmed in Mozambique, and other more certain and reliable biofuel crops could easily be substituted for it. Currently, there is little to no market in existence. It could be a few years before other economic and financial issues such as processing and transportation are addressed. It is natural that these companies encounter social matters as the jatropha industry is labor-intensive, and many permanent, part-time, and seasonal workers are needed to keep plantations operating. Also, as jatropha is a tree that requires natural and (in some cases) chemical inputs, and since large land areas are necessary for plantations, environmental aspects are always present.

The ethanol market of Brazil will be discussed to exemplify how a domestic market replacement of fossil fuels can be created. Currently, Brazil has the most advanced biofuel model in the world. In the 1970's Brazil began to implement and refine an ethanol fuel program, the first such model in the world. In 1976, the government required ethanol to be blended with gasoline, as well as requiring gasoline motors to be adjusted to accommodate blend rates of 10-22% (Rico, 2008). The government invested heavily in the ethanol sector to ensure its livelihood. Sugar cane, since it is so cheap to produce, allowed prices to remain low. In addition, Brazil has made sure to invest in agro technology and crop science. Although it took a long time and large investments by many parties, the ethanol replacement for gasoline has been a huge success.

For sugarcane workers, the wage is in most cases above the Brazilian minimum wage (Smeets, 2006). This is in contrast to Mozambique, where jatropha plantation workers are usually paid the
minimum agricultural wage, which is one of the lowest paid sectors. For workers families and surrounding communities, the Brazilian ethanol sector provides 600+ schools, 200+ nurseries and 300+ day-care centers. Furthermore, between 1-2% of the sugarcane price (net) must go to social infrastructure systems such as medical, dental, pharmaceutical, and sanitary services (Smeets, 2006).

It is possible for Mozambique to implement a similar model on social and economic levels. Mozambique's economy is based on agriculture, and almost all of the rural employment is agriculture-based (CIA World Factbook, 2008). The current plants in production for biofuel include sugar cane, sweet sorghum, copra, cotton, sunflower, and jatropha (Namburete, 2006). There is a total land area of 784,089 km² and 17,500 km² of inland water (Namburete, 2006). There are approximately 36 million hectares of arable land, and 9-15% is in agricultural use (Dagraca, 2007).

Jatropha could be introduced into the domestic market in two ways:

- Combining jatropha biodiesel petro diesel
- Introducing jatropha biodiesel as a petro diesel substitute

Most diesel car/truck engines manufactured after 1993 can run on 100% jatropha biodiesel because of the synthetic fuel lines in the diesel engine (AFIC Corporation, 2009). Before 1993, most cars were made with rubber fuel lines. These fuel lines tend to get clogged when biodiesel is used, and it is not recommended to run biodiesel through rubber lines unless they are replaced with synthetic ones. In Brazil, the government requires all car engines to be modified to run on certain percentages of ethanol-blended gasoline. The Mozambique government can impose something similar, to mandate that diesel engines must be equipped with synthetic fuel lines to accommodate for biodiesel/petro diesel blends. Even if engines are equipped with synthetic fuel lines, it is not recommended to immediately run the engine on 100% biodiesel. The jatropha biodiesel will sweep away all of the dirt in the engine as it passes by, and this will clog engine filters (AFIC Corporation, 2009). Normally, a blend of 5% biodiesel and 95% petro diesel is recommended as a start. This is similar to what Brazil did, as it gradually increased the percentage blend of ethanol in gasoline from 10% to 22% in 1976 to 25% as of 2009 (Rico, 2008).

Jatropha biodiesel could be distributed in the same way the petro diesel is distributed throughout the country—using the existing network of roads, ports, railways, and airports. In addition, it can be stored in the same facilities as petro diesel as long as some modifications are made to these structures. With jatropha produced throughout the country, rural areas could have access to this biodiesel as well.

6.5 International issues

Once jatropha is shipped to the E.U., the biodiesel can be fed into the petro diesel pipeline system, or pipelines specifically created for biofuel use. In 2006, the first biofuel pipeline was established in Austria (Munzer Bioindustrie, 2006). Biodiesel can be transported through existing petroleum pipelines without damaging the pipelines. However, one issue with biodiesel is that it can affect other diesel that is shipped through pipelines. When petro diesel is shipped through pipelines, it is moved in batches and tested on both ends of the pipe (McElroy, 2007). Because of the chemical make-up of biodiesel, small particles can be left inside the pipeline after biodiesel passes through (even at low-level blends) (McElroy, 2007). These particles can then become mixed in with petro diesel, causing contamination and possibly ended in negative test results after the petro diesel travels through the pipeline. In most cases, alternate transportation methods (such as truck) must be used because there is not enough research to provide evidence of non-contamination in pipeline transport. This is one issue adding to the expense of biofuels.

Jatropha biodiesel could easily be transported to an international market, specifically the European Union, where there is a heavy focus to find and use cleaner energy sources. The European Union has proposed a mandatory 10% minimum target of using renewable energy in the petro diesel sector by 2020 (The European Parliment and Council, 2009). Using the three shipping ports in
Jatropha curcas in Oahu and Mozambique—acknowledging scientific differences and resulting questions

Mozambique, jatropha biodiesel could be shipped to key harbors in Europe, and then integrated into the current petro diesel network. This would provide an increase in the transportation sector of Mozambique, and provide jobs in the jatropha sector.

Although this is the most likely direction jatropha plantations will take, it is not necessarily the best outcome for Mozambique as a whole. There will be a greater effect on Mozambique’s social and economic infrastructure if jatropha biodiesel is used in the local market. As previously mentioned, this will increase jobs, increase overall income, and keep more money in the country. If jatropha biodiesel is shipped to the E.U., it will help this alliance of countries reach their target, but jatropha from Mozambique will just be a small drop in the ocean of biodiesel. It will make a difference, but will not create the same impact as it would in Mozambique.

6.6 Jatropha compared to competing crops

The fact that jatropha can grow in agricultural wastelands distinguishes it from competing biofuel crops (for example rapeseed and soybean) as well as agricultural crops in general. Although the PPO market price is nearly the same between jatropha and competing biofuel crops.

The process of sowing to (full) harvest for jatropha can take upwards of 2 years: however, it is possible to harvest low amounts of fruit during the first year. In contrast, the soybean process takes 80-120 days and rapeseed takes 74-140 days. This puts jatropha at an immediate disadvantage because no money can be generated from the plants for at least 2 or 3 years.

The major issue with jatropha is its toxicity. Soybeans, for example, are non toxic and the remaining protein meal that is extracted during the crushing process can be used for a variety of food inputs both for humans and animals. In contrast, the protein meal from jatropha crushing and processing cannot be used for much apart from a jatropha field fertilizer. In countries with jatropha production, such as Mozambique, Tanzania, and India, the toxicity of the seedcake is not a cause for concern. In India and Africa, a portion of the seedcake is redistributed back to the jatropha fields, while the remainder is discarded. In the United States, the prevailing model is to find a use for all waste products, and to find a way to make money from it as well. Otherwise, the waste is just a cost, requiring extra expenditures to remove or discard them. Jatropha seeds contain up to 40% oil; the remaining 60% (minus a small amount for redistribution fertilizer and biomass) is unused. For every ton of jatropha oil, the waste is constituted of 1.25 tons of husks, 1 ton of hulls, and 1 ton of seedcake (Joos, 2009).

HARC has received non-toxic seeds from a German-based scientist. These seeds originate in Central America, and are a natural variation of jatropha. A non-toxic variety has multiple benefits; the main benefit is that the seedcake is essentially a high-protein meal that, if non-toxic, could be sold as an animal feed as an alternative to other high protein meals (such as rice and soy). On the island of Oahu, there are 450 cattle operations (beef cattle), 70 hog operations, 41 dairy operations, and 25 egg operations (Hawaii, 2004). All of these local operations could potentially use the high protein meal that jatropha could offer.

In a pre-analysis of jatropha meal carried out by the biofuel company D1, the protein, fiber, total digestible nutrient, and digestible energy levels exceeded those of soy meal, both solvent extracted and mechanically extracted. Yet, the problem still remains that there are anti-nutritional compounds and toxic elements found in the seedcake. The anti-nutritional compounds reduce nutrient utilization/feed intake in animals, and in general can cause negative physiological outcomes (D'Mello, 2000). D1 has carried out biological tests to find a way to remove the anti-nutritional compounds.

With competing crops such as corn and soy, crop yield, uniformity, etc., is essentially guaranteed and of course known and documented, due to intense seed breeding, crop study, and research. See Table 13 for an example of average output and prices for biofuel crops. This makes for simple harvest methods and predictions. These competing crops can be grown in Mozambique and are being promoted by some cities in Mozambique as well (Beira Corridor, 2010). For example, there is the potential in Mozambique to grow 6,100,000 hectares of maize, 2,300,000 hectares of sugarcane, and 1,600,000 hectares of soy (Beira Corridor, 2010).
Table 13. The price per hectare that competing biofuel crops can generate (Kurki et al., 2006).

<table>
<thead>
<tr>
<th>Crop</th>
<th>L/ha</th>
<th>mT/ha</th>
<th>Price per mT(USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palm oil</td>
<td>4752</td>
<td>4.8</td>
<td>1056</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>954</td>
<td>.954</td>
<td>257.58</td>
</tr>
<tr>
<td>Soy</td>
<td>554-922</td>
<td>.554-.922</td>
<td>138.5-230.5</td>
</tr>
<tr>
<td>Jatropha</td>
<td>770 (estimate)</td>
<td>0.77 (estimate)</td>
<td>192.5 (estimate)</td>
</tr>
</tbody>
</table>

Without accurate yield data, irrigation requirements, or domestication, it becomes nearly impossible to determine the economic viability of a plantation, and without this information, finding investors can be extremely difficult if not impossible. For some potential investors this unpredictability can pose severe problems. For competing, domesticated biofuel crops such as soybean and rapeseed, yield is certain and predictable. This data can lead to an easy choice for investors, especially when profit per hectare is known ahead of time.
Conclusion

Around the world there has been an increase in interest, and a resulting increase in investment towards jatropha. The investment is encouraged by governments, as well as large companies that have both the resources and capital to create what essentially are large-scale jatropha test plots. This is not to say that there is no jatropha market—in India, there is a thriving jatropha market due to the coordinated efforts of government and business. However, there is no consistent jatropha data or literature that has come from any country, and it is difficult to say if new jatropha models should be based on India, or if more scientific knowledge is required before embarking on serious projects in other parts of the world.

The initial aim was to identify and discuss jatropha as a biofuel crop in both Hawaii and Mozambique. In Hawaii, the government had commissioned HARC to research the crop assuming that it would be grown and processed in the United States. After 4+ years of research, test plots, and international trips, it was apparent that the basics (domestication, uniformity, input levels, farm equipment, etc.) had to be tackled before economic analyses and production could be determined. In Mozambique, international companies have invested in jatropha plantations due to the Mozambique government’s initiative. Although these plantations are supposed to be for actual production (as opposed to trial studies like the ones conducted in Hawaii), they are, in reality, test plots that are facing the same issues Hawaii has encountered. These plantations cannot move forward until yield levels are known and farm equipment (such as harvesters, crushers, storage containers, and transportation) is invented, modified, or built to accommodate for these plantations.

These points ran across the board, from local to government to economic to social. It is apparent that there are multiple areas that must be addressed both in the short and long term. If jatropha had problems in one, or even a few related areas, it would be easy for researchers and companies to work together and develop solutions or work arounds. However, the vast area of problems that surrounds jatropha makes it difficult to determine where to start, and what order to progress in. Each area that jatropha will grow in will also contain its subset of specific problem areas, creating more difficulties for companies and researchers.

When compared to existing biofuel crops, and taking into account the reality of where jatropha is planted, jatropha does not seem like the miracle crop it is supposed to be. Rather, it seems to (currently) be an unsuitable alternative to, for example, soy beans or rapeseed, which are already established and well researched and documented. It is unfortunate that jatropha is not explored as a biofuel crop that can grow on degraded land, as this is not a possibility for maize and many other biofuel crops. It is currently studied as a substitute to current biofuel crops and in many ways is losing the potential and characteristics that differentiate it from other biofuel crops.
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Bayer CropScience (2008) *Jatropha - This particular oil well holds a lot of future promise*. Bayer CropScience Editorial Services, Issue 1, 1.


Jatropha curcas in Oahu and Mozambique—acknowledging scientific differences and resulting questions


