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Jatropha: A Smallholder Bioenergy Crop

The Potential for Pro-Poor Development

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Jatropha: A Smallholder Bioenergy Crop

The Potential for Pro-Poor Development

Richard Brittaine
Agricultural Consultant
Reading, Berkshire, UK

NeBambi Lutaladio
Plant Production and Protection Division
FAO, Rome, Italy

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FOREWORD

As developing countries face increasing local demand for energy in rural areas, they also must deal with both economic and environmental pressure on agricultural lands in general. The possibility of growing energy crops such as *Jatropha curcas* L. has the potential to enable some smallholder farmers, producers and processors to cope with these pressures.

Jatropha is an underutilized, oil-bearing crop. It produces a seed that can be processed into non-polluting biodiesel that, if well exploited, can provide opportunities for good returns and rural development. In addition to growing on degraded and marginal lands, this crop has special appeal, in that it grows under drought conditions and animals do not graze on it.

However, many of the actual investments and policy decisions on developing jatropha as an oil crop have been made without the backing of sufficient science-based knowledge. Realizing the true potential of jatropha requires separating facts from the claims and half-truths.

This review is based on the records of the International Consultation on Pro-Poor Jatropha Development held in April 2008, in Rome, Italy, and hosted by the International Fund for Agricultural Development (IFAD), the Food and Agriculture Organization of the United Nations (FAO), the United Nations Foundation (UNF) and the Prince Albert II of Monaco Foundation. The consultation was designed to support activities aimed at developing appropriate technologies for sustainable intensification of biofuel feedstock production, studying the economics of bioenergy for rural needs and assessing its impact on rural poverty.

The review provides a brief overview of biofuels, their growth drivers and their potential impacts on poor societies. It looks at how jatropha, which originated in Central America and then spread across Africa and Asia, has become widespread throughout the tropics and subtropics. It also builds upon technical and scientific information on key issues affecting jatropha for pro-poor development that was presented during the Consultation by specialists from around the world.

The review also summarizes the most recent data on the cultivation, seed harvesting and processing, uses and genetic improvement of jatropha, and it offers an overview and case studies of experiences with jatropha production in sub-Saharan Africa and South Asia. It concludes with viewpoints gathered from the Consultation's group discussions and roundtables that recognized the importance of biofuels and the potential of jatropha biofuel development for poverty reduction, but also emphasized the need to consider potential risks to food security, the environment and livelihoods of the rural poor.

This publication seeks to contribute to strengthening jatropha policies and strategies in developing countries – policies that recognize the potential of jatropha to contribute towards pro-poor development, sustain rural income and improve livelihoods. We trust that it will provide valuable guidance to government and institutional policy- and decision-makers, and that it will be a valuable source of information for programme managers, international and multilateral development organizations, donors, NGOs, the private sector and foundations as well as researchers, advisors, teachers and professionals in agriculture.

Shivaji Pandey
Director, Plant Production and Protection Division
Food and Agriculture Organization of the United Nations

Rodney Cooke
Director, Technical Advisory Division
International Fund for Agriculture Development

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Eric A. Kueneman
Deputy Director
FAO Plant Production and
Protection Division

Vineet Raswant
Senior Technical Adviser
International Fund for
Agriculture Development

Photo: FAIDUTTI

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ACRONYMS AND ABBREVIATIONS

B5	Blend of 5 percent biodiesel with mineral diesel
Ca	Calcium
CDM	Clean development mechanism
CGIAR	Consultative Group on International Agricultural Research
CO_2	Carbon dioxide
CPR	Common property resource
Cu	Copper
DAP	Diammonium phosphate
DM	Dry matter
DWMA	District Water Management Agency
E5	Blend of 5 percent bioethanol with petrol
EMPPO	European and Mediterranean Plant Protection Organization
ET	Evapotranspiration
ETBE	Ethyl Tertiary Butyl Ether
FACT	Fuels from Agriculture in Communal Technology
FAO	Food and Agriculture Organization of the United Nations
Fe	Iron
GDP	Gross Domestic Product
GHG	Greenhouse gas
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
HH	Household
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
JME	Jatropha methyl ester
K	Potassium
K_2O	Potassium oxide
Kcals	Kilocalories
Kg	Kilogram
kW	Kilowatt
LCA	Life cycle analysis
LIFDC	Low-income food-deficit country

MFP	Multifunctional platform
Mg	Magnesium
mg	Milligram
MJ	Megajoule
Mn	Manganese
N	Nitrogen
N_2O	Nitrous oxide
n.d.	No date
NGO	Non-governmental organization
NOVOD	National Oilseeds and Vegetable Oils Development Board
OECD	Organisation for Economic Co-operation and Development
P	Phosphate
RME	Rape methyl ester
R	Indian rupee
S	Sulphur
SSP	Single super phosphate
SVO	Straight vegetable oil
TZS	Tanzanian shillings
ULSD	Ultra low sulphur diesel
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organization
VOME	Vegetable oil methyl ester
Zn	Zinc

EXECUTIVE SUMMARY

Declining reserves of fossil fuels plus recognition that growing carbon dioxide emissions are driving climate change have focused world attention on the need to reduce fossil fuel dependence. In turn, this has increased interest in promoting bioenergy, including biofuels, as a renewable energy source.

Liquid biofuels have the potential to help power the transportation sector. Considering that transportation is responsible for some 30 percent of current energy usage and that biofuels can be used in transportation with only few changes to the existing distribution infrastructure, biofuels become an extremely important form of bioenergy. Producing liquid biofuels from food crops using conventional technology is also being pursued as a means of farm income support and for driving rural development. However, the debate around biofuels is creating a lot of uncertainty and will continue to do so until it can be shown that biofuels can be low-cost, low-carbon and sustainable, and do not endanger food security.

Given the sheer size of the energy market compared to the market for agricultural commodities, the potential for biofuels alone to address climate change and energy security is quite limited. However, the increased demand for biofuels does create a huge new market for agricultural products. Liquid biofuels generally require large-scale production and processing to be viable, although this is less true where the end product is straight vegetable oil rather than either bioethanol or biodiesel.

Interest in *Jatropha curcas* as a source of oil for producing biodiesel has arisen as a consequence of its perceived ability to grow in semi-arid regions with low nutrient requirements and little care. The seed typically contains 35 percent oil which has properties highly suited to making biodiesel. Unlike other major biofuel crops, jatropha is not a food crop since the oil is non-edible and is, in fact, poisonous. It is a low growing oil-seed-bearing tree that is common in tropical and subtropical regions where the plant is often used in traditional medicine and the seed oil is sometimes used for lighting. The tree is occasionally grown as a live fence for excluding livestock and for property demarcation. The rooting nature of jatropha allows it to reach water from deep in the soil and to extract leached mineral nutrients that are unavailable to many other plants. The surface roots assist in binding the soil and can reduce soil erosion.

In 2008, jatropha was planted on an estimated 900 000 ha globally – 760 000 ha (85 percent) in Asia, followed by Africa with 120 000 ha and Latin America with 20 000 ha. By 2015, forecasts suggest that jatropha will be planted on 12.8 million ha. The largest producing country in Asia will be Indonesia. In Africa, Ghana and Madagascar will be the largest producers. Brazil will be the largest producer in Latin America.

Jatropha has a number of strengths: the oil is highly suitable for producing biodiesel but can also be used directly to power suitably adapted diesel engines and to provide light and heat for cooking, it is fast growing and quick to start bearing fruit, and the seed is storable making it suited to cultivation in remote areas. Jatropha could eventually evolve into a high yielding oil crop and may well be productive on degraded and saline soils in low rainfall areas. Its by-products may possibly be valuable as fertilizer, livestock feed, or as a biogas feedstock, its oil can have other markets such as for soap, pesticides and medicines, and jatropha can help reverse land degradation.

Jatropha's chief weaknesses relate to the fact that it is an essentially wild plant that has undergone little crop improvement. Its seed yields, oil quality and oil content are all highly variable. Most of the jatropha currently grown is toxic which renders the seedcake unsuitable for use as livestock feed and may present a human safety hazard. Fruiting is fairly continuous which increases the cost of harvesting. Knowledge of the agronomy of jatropha and how agronomic practices contribute to yield is generally lacking. Furthermore, there is an unknown level of risk of *Jatropha curcas* becoming a weed in some environments.

Optimum growing conditions are found in areas of 1 000 to 1 500 mm annual rainfall, with temperatures of 20°C to 28°C with no frost, and where the soils are free-draining sands and loams with no risk of water-logging. Propagation is typically from seed. Cuttings offer the benefit of uniform productivity with the disadvantage that they do not generally develop a tap root. The production of clonal and disease-free plants using tissue culture is not yet a commercial reality. Attention to crop husbandry and adequate nutrition and water are essential to achieving high yields. Pruning is important to increase the number of flowering branches.

Crop improvement is at an early stage. Increasing oil yield must be a priority – an objective that has only recently been addressed by private enterprise. Genetic variation among known *Jatropha curcas* accessions may be less than previously thought, and breeding inter-specific hybrids may offer a promising route to crop improvement. Jatropha displays considerable genetic–environment interaction, meaning that different clones may appear and perform very differently under different environmental conditions. Short-term goals should aim at producing superior clonal plants using cuttings and/or cell culture techniques, with longer term goals aimed at developing improved varieties with reliable trait expression and with a seed production system that ensures farmer access to productive and reliable planting materials.

In terms of its viability as a cash crop, experience with jatropha production in sub-Saharan Africa and South Asia has found that yields are marginal, at best. Reported yields have been between 1 and 1.6 tonnes per ha. Holistic schemes that embrace jatropha production, oil extraction and utilization in remote rural communities appear the most viable, particularly where its other benefits are recognized, such as reversing land degradation. Jatropha production systems can be characterized in terms of their direct or indirect potential contribution to pro-poor development. It is expected that large plantations developed by the private sector will predominate in the future and that smallholders may be contract farmers for such commercial enterprises.

Jatropha biofuel production could be especially beneficial to poor producers, particularly in semi-arid, remote areas that have little opportunity for alternative farming strategies, few alternative livelihood options and increasing environmental degradation. While there are various possibilities for utilizing the by-products of jatropha – which would add value for the producers and reduce the carbon cost of the oil as a biofuel – there is an important trade-off between adding value and utilizing the by-products as soil ameliorants to reverse land degradation. Local utilization of jatropha oil is one of a number of strategies that may be used to address energy poverty in remote areas and could be part of production systems or part of a "living fence" to control livestock grazing.

The expectation that jatropha can substitute significantly for oil imports will remain unrealistic unless there is an improvement in the genetic potential of oil yields and in the production practices that can harness the improved potential. For the present, the main pro-poor potential of jatropha is within a strategy for the reclamation of degraded farmland along with local processing and utilization of the oil and by-products. In addition, by providing physical barriers, jatropha can control grazing and demarcate property boundaries while at the same time improving water retention and soil conditions. These attributes, added to the benefits of using a renewable fuel source, can contribute in an even larger way to protecting the environment.

Photo: FAIDUTTI

CHAPTER 1

Introduction

Since the surge of interest in renewable-energy alternatives to liquid fossil fuels hit in 2004/5, the possibility of growing *Jatropha curcas* L. for the purpose of producing biofuel has attracted the attention of investors and policy-makers worldwide. The seeds of jatropha contain non-edible oil with properties that are well suited for the production of biodiesel.

Although optimum ecological conditions for jatropha production are in the warm subhumid tropics and subtropics, jatropha's ability to grow in dry areas on degraded soils that are marginally suited for agriculture makes it especially attractive. In addition, jatropha can be used as a living fence to keep out livestock, control soil erosion and improve water infiltration. The waste products from jatropha biodiesel production can be used as fertilizer and for producing biogas, and the jatropha seedcake can potentially be used for livestock feed.

Although there have been increasing investments and policy decisions concerning the use of jatropha as an oil crop, they have been based on little evidence-based information. There are many knowledge gaps concerning the best production practices and the potential benefits and risks to the environment. Equally troubling is that the plant is in an early stage of domestication with very few improved varieties. Identifying the true potential of jatropha requires separating the evidence from the hyped claims and half-truths.

This publication reviews the information currently available on jatropha as a bioenergy crop, starting with the papers presented to the April 2008 IFAD/FAO International Consultation on Pro-Poor Jatropha Development held in Rome, Italy (IFAD 2008). This information has been supplemented by consulting various reports, conference papers, and both published and unpublished scientific papers.

Based on the output of the International Consultation, the aim of this report is to identify the jatropha production systems that are most sustainable and viable and that can contribute to rural development and alleviate poverty. It also points out the critical areas of needed research, trusting that this information will be useful for decision-makers as well as for those actively involved in jatropha production.

This introductory chapter offers general background on liquid biofuels, energy poverty and global jatropha production trends.

BIOFUELS – AN OVERVIEW

Bioenergy and biofuels

Bioenergy is a renewable, non-fossil energy obtained from the combustion of biomass, most often in the form of fuelwood, biogas or liquid biofuel. Liquid biofuels can be bioethanol, biodiesel or straight vegetable oil. While bioethanol (ethyl alcohol) is a chemical compound, biodiesel is a mixture of compounds that varies in physical properties according to the feedstock used to produce it. Liquid biofuels can replace petrol and diesel for transport use and can be used in stationary engines to generate electricity, pump water and mill food grains as well as for cooking and lighting.[1]

First, second and third generation biofuels

Levels of technological development for biofuels are defined as first, second and third generation (CGIAR 2008). First generation biofuels, which are the fuels now in common use, derive mainly from food crops by utilizing conventional technology. The important biofuel crops are maize, sugar cane and sugar beet for the extraction of sugars to produce

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1 The prospective risks and opportunities of these fuels and their impacts on agriculture and food security are described in the *2008 FAO State of Food and Agriculture* (SOFA).

bioethanol, and soybean, rapeseed and oil palm for the extraction of oil to produce biodiesel.

Technologies for second and third generation biofuels remain under development. They offer the prospect of producing biofuels from non-food sources such as fast-growing trees, grasses and carbon-rich waste materials. These future technologies will also have the capability of converting algae and bacteria into oils that can replace petroleum fuels.

The need to optimize resources and minimize waste also has prompted research into the production of higher value chemicals and commodities as by-products of biofuel feedstock processing. Brazil's sugarcane industry has adopted this bio-refinery concept, using the waste bagasse left after sucrose extraction as a fuel to produce electricity.

Bioethanol and biodiesel

Bioethanol: Sucrose is extracted from the plant stem or tuber of sugar-rich crops, fermented and then distilled to produce bioethanol (alcohol). Crops rich in starch, such as maize and cassava, need a pre-treatment to convert the starch into fermentable sugars. Bioethanol is commonly blended with petrol in proportions of up to 5 percent (E5) for which no engine modification is required.

Biodiesel: Trees, shrubs and herbaceous oilseed plants may be used for the production of biodiesel through trans-esterification – a process by which alcohol is added to vegetable oil in the presence of a catalyst. The seeds of oil-rich plants are hulled and pressed to extract the oil which is then filtered. Methanol is added to the raw vegetable oil, using sodium (or potassium) hydroxide as the catalyst. The product is a vegetable oil methyl ester (VOME) or, in the case of jatropha, jatropha methyl ester (JME). Biodiesel has very similar properties to petroleum diesel. The main by-product of this process is glycerine, which also has diverse commercial uses. Biodiesel may be directly substituted for petroleum diesel (gas oil) in blends of up to 5 percent (B5) without engine modification.

Figure 1 illustrates the basic processes of converting plants to transport fuels.

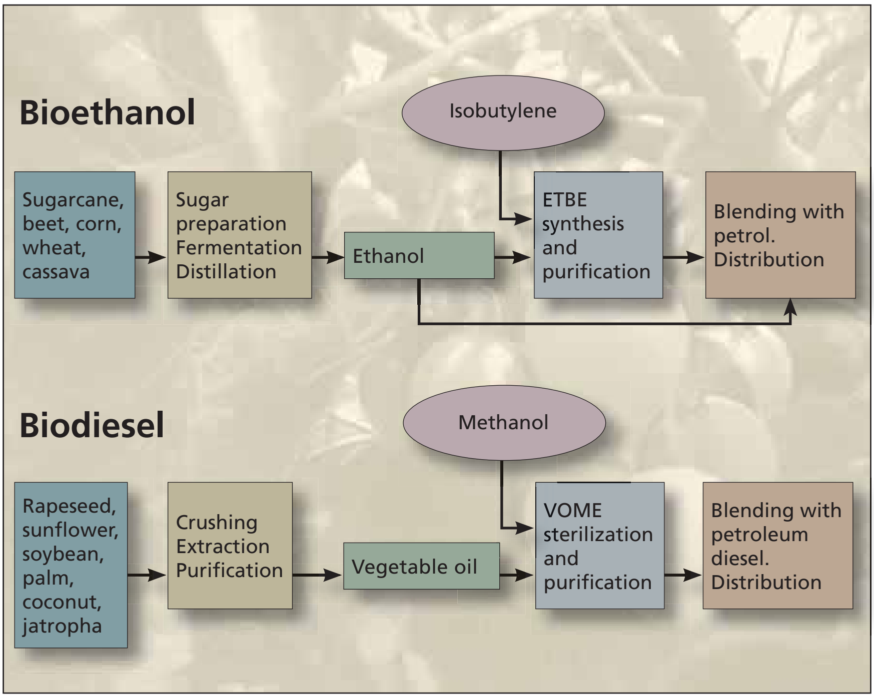


FIGURE 1: Bioethanol and biodiesel production processes

Straight vegetable oil

Extracted and filtered vegetable oil can be used directly as a fuel in suitable diesel engines without undergoing the trans-esterification process (Achten *et al.*, 2008). While there are issues with poor performance, increased maintenance, reduced engine life and engine manufacturers who void warranties if vegetable oils are used, there is now considerable experience with using straight vegetable oil in suitably modified diesel engines (de Jongh and Adriaans, 2007; Cloin, 2007).

GROWTH DRIVERS OF BIOFUELS

Growth of the biofuel industry is being driven by government policies in three main areas. This includes policies aimed at mitigating climate change, improving energy security and using biofuel production as a strategy to support rural development.

Mandates and targets for inclusion of biofuels in petrol and diesel, together with subsidies and border protection in the form of import tariffs and quotas, are the means by which governments provide the impetus to drive biofuel growth. The United States of America (USA) leads in production-related subsidies while other countries, including the European Union (EU) and Brazil, largely use tax exemptions as the policy instrument for the promotion of biofuels.

Climate change

The need to slow or reverse global warming is now widely accepted. This requires reduction of greenhouse gas (GHG) emissions, especially reduction of carbon dioxide emissions. Using cultivated and non-domesticated plants for energy needs instead of fossilized plant remains such as mineral oil and coal reduces the net addition of CO_2 to the atmosphere. In addition, biodiesel produces fewer particulates, hydrocarbons, nitrogen oxides and sulphur dioxides than mineral diesel and therefore reduces combustion and vehicle exhaust pollutants that are harmful to human health.

Energy security

The search for renewable energy is being driven by volatile crude oil prices and the perceived threat to national security of over-dependence on foreign supplies. Crude oil prices are likely to increase over the long term as fossil reserves diminish and global demand increases, particularly in the newly emerging economies of Asia and Latin America.

However, the potential of biofuels to enhance energy security is limited. Globally, the huge volume of biofuels required to substitute for fossil fuels is beyond the capacity of agriculture with present day technology. For example in 2006/7, the USA used 20 percent of its maize harvest for ethanol production, which replaced only three percent of its petrol consumption (World Bank, 2008). More significant displacement of fossil fuels will be likely with second and third generation biofuels (SOFA, 2008).

Rural development

Government policy in support of rural development, the third main driver of biofuel growth, has been enabled by the large demand for biofuel feedstocks and the import substitution potential of biofuels. In OECD countries, biofuels are seen as a new market opportunity due to their ability to absorb surplus agricultural production while maintaining productive capacity in the rural sector. In developing countries, biofuels can contribute to rural development in three main areas: employment creation, income generation and by replacing traditional biomass, which is an inefficient and unsustainable energy resource, with modern and sustainable forms of bioenergy.

Economies of scale and the vertical integration required for biofuel production allow little scope for small farmers to benefit. This is particularly true in bioethanol production and will be even more so with second- and third-generation biofuels, unless specific efforts are made to include small farmers in biofuel production schemes. There is more potential for biodiesel to be produced on a smaller scale, although maintaining consistent quality standards will be a problem. Small-scale production of straight vegetable oil requires the least economies of scale and has the greatest potential to benefit small farmers and rural development.

THE IMPORTANCE OF THE TRANSPORT SECTOR

Transportation is responsible for some 30 percent of current global energy usage, practically all in the form of diesel or petrol. Using current technology, biofuels offer the most convenient renewable alternative to fossil transport fuels since they require the fewest changes to the distribution infrastructure. Biofuels produced in sufficient volume could make a significant impact on global warming since it is estimated that transport accounts for 21 percent of total greenhouse gas emissions (Watson *et al.*, 1996). Consumption of total liquid fuels will grow by more than a third during the period 2005 to 2030 and, as Figure 2 illustrates, nearly three quarters of this increased demand is expected to come from the transport sector.

PRODUCTION AND CONSUMPTION

Bioethanol is the biofuel most widely used for transportation worldwide. The global annual production of fuel ethanol is around 40 billion litres, of which 90 percent is produced by the USA from maize and by Brazil from

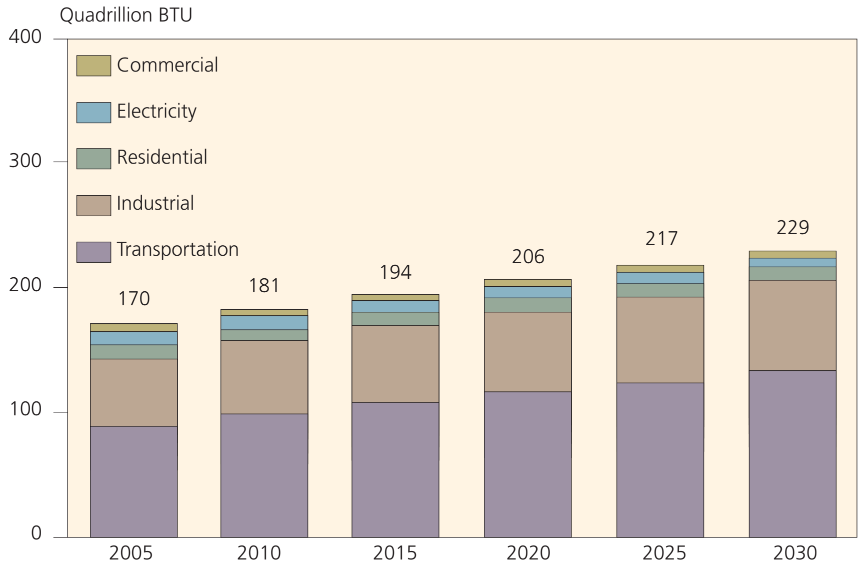


FIGURE 2: **World liquid fuels consumption by sector 2005-2030**

Source: Energy Information Administration (2008).

sugarcane (World Bank, 2008). Global ethanol production has seen steady growth since the search for alternatives to petroleum was prompted by the oil crisis of 1973/4. The USA is now the largest consumer of bioethanol, followed by Brazil. Together they consume 30 billion litres, or three quarters of global production (Licht, 2005).

Global annual production of biodiesel – around 6.5 billion litres – is small compared to bioethanol. The main biodiesel feedstocks are soybean and rapeseed, with the main producers in the Americas and the EU respectively. The EU is by far the largest producer of biodiesel, responsible for 95 percent of world output.

In humid tropics, oil palm is the most important biodiesel feedstock, with Indonesia leading in production followed by Malaysia. Indonesia is projected to increase biodiesel production from 600 million litres in 2007 to 3 billion litres by 2017, which will make it the world's largest producer of palm oil and the second largest producer of biodiesel.

A 2008 analysis by the Energy Information Administration found that nearly half of the increase in world biofuel production between now and 2030 will come from the USA.

THE IMPACTS OF BIOFUELS AND THEIR SUSTAINABILITY

Quantifying how biofuels reduce GHG emissions and how energy efficient they are requires life-cycle analyses (LCAs). LCAs call for a great deal of data and, ideally, take full account of all stages of the production and use of a biofuel, including the GHG emissions and energy efficiencies associated with the resources required for its production. While a fully comprehensive LCA is not yet available, Figure 3 presents a limited LCA of jatropha.

Work in this area shows that the life-cycle energy balance improves and global warming potential decreases when cultivation is less intensive, particularly with less fertilizer and less irrigation, and if the end product is straight vegetable oil rather than biodiesel. The energy-efficient use of the by-products also significantly improves the sustainability and environmental impact of biofuels. However, without plant nutrient management, vegetable oil yields and production will decline – indicating a trade-off between low cultivation intensity and productivity.

Figure 3 shows the energy input required to produce jatropha biodiesel (JME) and offers a comparison with the production of rapeseed biodiesel (RME – rapedseed methyl ester) and mineral diesel. The top horizontal

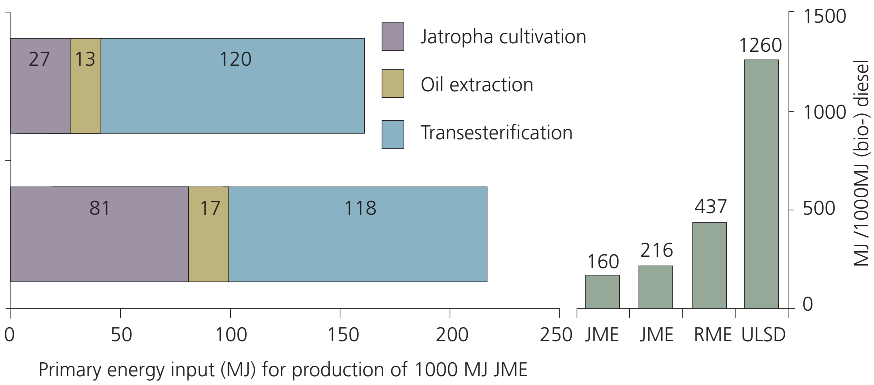


FIGURE 3: **Energy input for the production of jatropha biodiesel at two cultivation intensities, left, and compared to rapeseed methyl ester and mineral diesel, right.**

Source: Tobin and Fulford, cited in Achten *et al.* (2008).

bar, which shows the energy required to produce JME at low cultivation intensity, illustrates that the energy used in cultivation is 17 percent of the total energy input. The lower bar illustrates a higher cultivation intensity, in which cultivation requires 38 percent of the total energy input. The vertical bars to the right show these energy efficiencies for jatropha against the poorer efficiencies of producing biodiesel from rapeseed and for producing mineral ultra low sulphur diesel (ULSD).

However, these analyses do not account for nitrous oxide (N_2O) emissions that result from nitrogen (N) fertilization. N_2O is a gas with a very high global warming potential. Furthermore, it should be noted that clearing natural vegetation to plant jatropha has a negative effect on the GHG balance. Fargione *et al*. (2008) found that converting rainforest, peatlands, savannahs or grasslands to the growing of biofuel crops releases 17 to 420 times more CO_2 than the reductions that occur when these biofuels replace fossil fuels. This underscores the fact that growing jatropha on degraded wastelands with minimal fertilizers and irrigation will have the most positive environmental impact.

Biofuel production also impacts the environment through its effect on water resources and biodiversity. Declining availability of water for irrigation, most notably in India and China, necessitates using the most water-efficient biofuel crops and cropping systems for long-term sustainability. The use of degraded land, conservation agriculture techniques with minimal soil disturbance and permanent soil cover, intercropping and agroforestry systems will lessen negative environmental impact. Biodiversity will be threatened by large-scale monocropping of exotic species.

The main social impacts of biofuels are in the areas of food security, poverty, employment and access to land. Large-scale biofuel schemes – those that require employed labour – have the potential to reduce access to land where land tenure systems are weak, and people may become worse off if there are few checks and controls on employment conditions.

Using food crops for biofuels drives up prices. This means that biofuels are likely to increase the incidence and depth of poverty by making food more costly for net food buyers who account for more than half of the rural poor in developing countries (World Bank, 2008). Certainly in the short term, the majority of poor people will be made poorer by higher food prices.

However, biofuels may also present a significant economic opportunity for the rural poor who mostly rely on agriculture for their livelihoods. Biofuel demand can reverse the long-term decline in real agricultural prices. It is an opportunity for greater investment in agriculture that can lead to higher productivity in industrial crops and food crops, and increased rural employment.

ENERGY POVERTY AND BIOENERGY IN POOR SOCIETIES

The link between poverty alleviation and energy provision makes it critical to consider both when looking toward rural development. Availability of local energy and farm power is fundamental to intensifying agriculture, and agricultural development is essential to poverty alleviation. There is a growing consensus among policy-makers that energy is central to reducing poverty and hunger, improving health, increasing literacy and education, and improving the lives of women and children. Energy pervades all aspects of development – it creates healthier cooking environments, extends work and study hours through the provision of electric light, provides power in remote regions to drive cellular communication equipment, and increases labour productivity and agricultural output by making mechanization possible.

Energy poverty is widespread in the developing world but, as shown in Figure 4, large differences exist among countries. More emphasis could be put on bioenergy as a solution to the needs of the 1.6 billion people who lack access to electricity and on its potential to improve the lives of the 2.4 billion who use traditional biomass (wood fuels, agricultural by-products and dung) for their energy needs. Traditional biomass accounts for 90 percent of energy consumption in poor countries but is often unhealthy, inefficient and environmentally unsustainable.

Two-thirds of the low-income food-deficit countries (LIFDCs) for which data exist are also energy deficient, with 25 of the 47 poorest countries totally dependent on imported fuels. These countries use much of their available funds to import oil with little left to support economic growth.

Oil-importing poor countries have been hit hardest by higher oil prices that have worsened their balance of payments. Biofuels development could improve their foreign exchange reserves, either by substituting for oil imports or by generating revenues through biofuel exports.

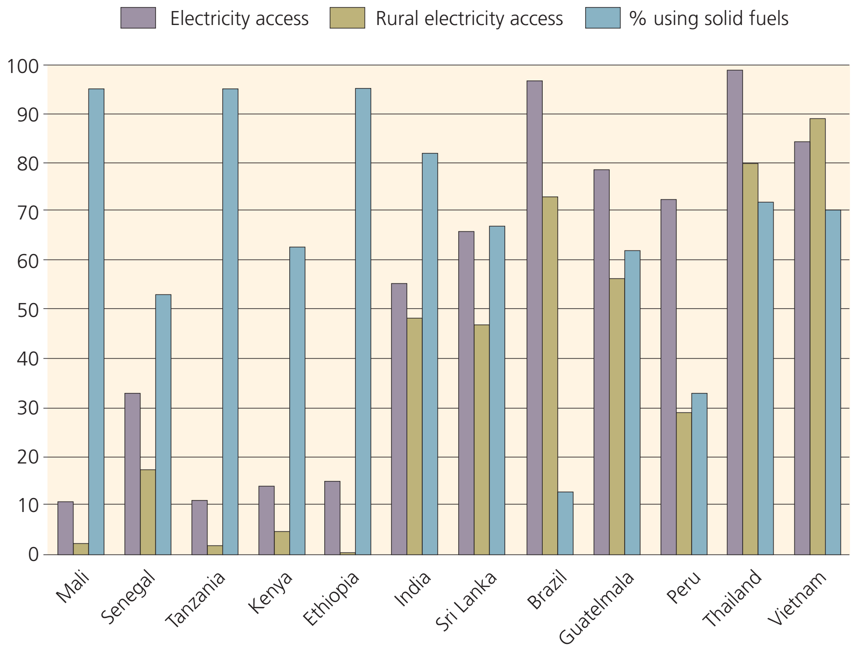


FIGURE 4: **Energy access characteristics for selected countries.**

Source: Practical Action Consulting (2009).

Brazil substitutes sugar for oil

Brazil's use of home-grown biofuels is often held up as an example of oil import substitution. The oil crisis of the 1970s kick-started Brazil's ethanol-from-sugarcane industry, which initially required considerable state subsidies. Now, the industry is not only self sustaining, it has been responsible for savings of more than USD 100 billion, with Brazil using locally produced bioethanol instead of importing oil. At the same time, it has made Brazil the world's largest exporter of sugarcane-derived bioethanol (Moreira, 2006). Land availability and suitable agroclimatic conditions of Brazil played important parts in the success of this initiative. Brazil is now promoting the production of sugarcane on degraded pasture lands, thus providing environmental services as well as economic growth.

However, addressing energy poverty in remote rural areas requires more than relying on biofuel crop production to raise incomes. There is a need to have sustainable systems of biofuel production, processing and simple utilization technology in place.

JATROPHA – GLOBAL AND REGIONAL PRODUCTION AND TRENDS

The jatropha industry is in its very early stages, covering a global area estimated at some 900 000 ha. More than 85 percent of jatropha plantings are in Asia, chiefly Myanmar, India, China and Indonesia. Africa accounts for around 12 percent or approximately 120 000 ha, mostly in Madagascar and Zambia, but also in Tanzania and Mozambique. Latin America has approximately 20 000 ha of jatropha, mostly in Brazil.

The area planted to jatropha is projected to grow to 4.72 million ha by 2010 and 12.8 million ha by 2015. By then, Indonesia is expected to be the largest producer in Asia with 5.2 million ha, Ghana and Madagascar together will have the largest area in Africa with 1.1 million ha, and Brazil is projected to be the largest producer in Latin America with 1.3 million ha (Gexsi, 2008).

CHAPTER 2

Jatropha curcas L.

ORIGIN AND SPREAD

Jatropha is believed to have been spread by Portuguese seafarers from its centre of origin in Central America and Mexico via Cape Verde and Guinea Bissau to other countries in Africa and Asia. It is now widespread throughout the tropics and sub-tropics.

Until recently, jatropha had economic importance in Cape Verde. Since the first half of the nineteenth century, with its ability to grow on poor soils with low rainfall, it could be exploited for oilseed production. Cape Verde exported about 35 000 tonnes of jatropha seeds per year to Lisbon. Along with Madagascar, Benin and Guinea, it also exported jatropha seeds to Marseille where oil was extracted for soap production. However, this trade declined in the 1950s with the development of cheaper synthetic detergents and, by the 1970s, the trade in jatropha oil had disappeared (Wiesenhütter, 2003; Henning, 2004a).

In the past, jatropha oil was used for lighting lamps (Gübitz *et al*., 1998). Today, rural communities continue to use it for its medicinal value and for local soap production. India and many countries in Africa use the jatropha plant as a living hedge to keep out grazing livestock. Jatropha is planted in Madagascar and Uganda to provide physical support for vanilla plants.

Jatropha's potential as a petroleum fuel substitute has long been recognized. It was used during the Second World War as a diesel substitute in Madagascar, Benin and Cape Verde, while its glycerine by-product was valuable for the manufacture of nitro-glycerine.


Photo: BRITTAINE

PLATE 1: ***Jatropha curcas*** L., Andhra Pradesh, India.

NOMENCLATURE AND TAXONOMY

Jatropha curcas L. (see Plate 1) was first described by Swedish botanist Carl Linnaeus in 1753. It is one of many species of the genus *Jatropha*, a member of the large and diverse *Euphorbiaceae* family. Many of the *Euphorbias* are known for their production of phytotoxins and milky white sap. The common name "spurge" refers to the purgative properties of many of these *Euphorbias*.

There are some 170 known species of jatropha, mostly native to the New World, although 66 species have been identified as originating in the Old World (Heller, 1996). A number of jatropha species are well known and widely cultivated throughout the tropics as ornamental plants. The literature identifies three varieties: Nicaraguan (with larger but fewer fruits), Mexican (distinguished by its less-toxic or non-toxic seed) and Cape Verde. The Cape Verde variety is the one commonly found throughout Africa and Asia. *Jatropha curcas* L. has many vernacular names including: physic nut or purging nut (English), *pinhão manso* or *mundubi-assu* (Brazil), *pourghère* (French), *purgeernoot* (Dutch), *Purgiernuss* (German), *purgeira* (Portuguese), *fagiola d'India* (Italian), *galamaluca* (Mozambique), *habel meluk* (Arab), *safed arand* (Hindi), *sabudam* (Thai), *bagani* (Ivory Coast), *butuje* (Nigeria), *makaen* (Tanzania), *piñoncillo* (Mexico), *tempate* (Costa Rica) and *piñon* (Guatemala).

DESCRIPTION

Jatropha, a succulent perennial shrub or small tree, can attain heights of more than 5 metres, depending on the growing conditions. The photos in Plates 2 and 3, taken in Andhra Pradesh, India, clearly show the effect of water and nutrient stress on plant size. In each case, the trees are slightly more than two years old.

Seedlings generally form a central taproot, four lateral roots and many secondary roots. The leaves, arranged alternately on the stem, are shallowly lobed and vary from 6 to 15 cm in length and width (see Plate 4). The leaf size and shape can differ from one variety to another. As with other members of this family, the vascular tissues of the stems and branches contain white latex. The branches and stems are hollow and the soft wood is of little value.

Jatropha is monoecious, meaning it carries separate male and female flowers on the same plant. There are fewer female than male flowers and these are carried on the apex of the inflorescence, with the more numerous males borne lower down. The ratio of male to female flowers averages 29:1 but this is highly variable and may range from 25-93 male flowers to 1-5 female flowers produced on each inflorescence (Raju and Ezradanum,

Photo: BRITTAINE

PLATE 2: Jatropha with adequate water and nutrients.

Photo: BRITTAINE

PLATE 3: Jatropha growing in dry marginal soils.

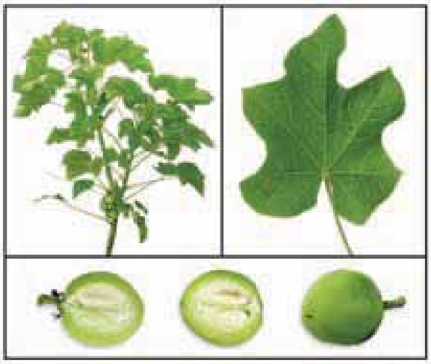


Photo: GODOFREDO STUART

PLATE 4: **Jatropha leaf and fruit.**

Photo: HENNING

PLATE 5: **Jatropha flowers.**

2002). It also has been reported that the male-to-female flower ratio declines as the plant ages (Achten *et al.*, 2008), suggesting that fruiting capacity may increase with age.

The unisexual flowers of jatropha (see Plate 5) depend on pollination by insects, including bees, flies, ants and thrips. One inflorescence will normally produce 10 or more fruits. Fruit set generally results from cross pollination with other individual plants, because the male flowers shed pollen before the female flowers on the same plant are receptive. In the absence of pollen arriving from other trees, jatropha has the ability to self pollinate, a mechanism that facilitates colonization of new habitats (Raju and Ezradanum, 2002).

The fruits are ellipsoidal, green and fleshy, turning yellow and then brown as they age. Fruits are mature and ready to harvest around 90 days after flowering. Flowering and, therefore, fruiting are continuous, meaning that mature and immature fruits are borne together. Each fruit contains two or three black seeds, around 2 cm x 1 cm in size. On average, the seeds contain 35 percent of non-edible oil. The immature and mature fruits are shown together with the seed in Plate 6.

Jatropha grows readily from seed which germinate in around 10 days, or from stem cuttings. Growth is rapid. The plant may reach one metre and flower within five months under good conditions (Heller, 1996). The growth is sympodial, with terminal flower inflorescences and lateral branching, eventually reaching a height of 3 to 5 metres

Photo: BRITTAINE

PLATE 6: Jatropha fruit and seeds.

under good conditions. It generally takes four to five years to reach maturity (Henning, 2008a).

Vegetative growth occurs during the rainy season. During the dry season, there is little growth and the plant will drop its leaves. Flowering is triggered by rainfall and seed will be produced following the end of the rainy season. Seeds are produced in the first or second year of growth. Jatropha trees are believed to have a lifespan of 30 to 50 years or more.

USES OF JATROPHA

With the present interest in the energy-producing potential of jatropha, it is useful to look at the attributes, both positive and negative of the plant, and to compare the relative energy values of its different parts. Figure 5 (see page 21) presents a summary of the various uses of jatropha that have been reported in relation to their energy values. It is interesting to note that the energy content of the remaining parts of the fruit after oil extraction exceeds the energy content of the oil.

The jatropha tree

Erosion control and improved water infiltration

Jatropha has proven effective in reducing the erosion of soil by rainwater. The taproot anchors the plant in the ground while the profusion of lateral and adventitious roots near the surface binds the soil and keeps it from being washed out by heavy rains. Jatropha also improves rainwater infiltration when planted in lines to form contour bunds. Furthermore, jatropha hedges reduce wind erosion by lessening wind velocity and binding the soil with their surface roots (Henning, 2004a).

Photo: MALI-FOLKECENTRE

PLATE 7: **Jatropha hedge in Mali, West Africa.**

Photo: GOERGEN

PLATE 8: **Jatropha hedge planted with agave, Madagascar.**

However, these anti-erosion effects are limited by dry season leaf drop. This means there is less protection at a time when wind erosion is highest and there is no leaf canopy to protect the soil when the first heavy rains fall. This can be ameliorated by growing drought-resistant ground cover plants such as agave, as shown in Plate 8. It appears that jatropha has little negative allelopathic effect on other plants (Weisenhutter, 2003).

Livestock barrier and land demarcation

In many tropical and subtropical countries, jatropha cuttings are planted as a hedge to protect gardens and fields from wandering animals (see Plates 7 and 8). Livestock will not eat the mature leaves and even goats will die of starvation if there is only jatropha to browse (Henning, 2004a). For the same reason, jatropha is often planted to mark homestead boundaries. Hedges planted very close together (5 cm) form a barrier that is impenetrable even by chickens.

Fuelwood

The wood of jatropha is soft and hollow and, contrary to some reports in the literature, is not good fuelwood. Jatropha groves on the islands of

Cape Verde have been used as a fuelwood source, mainly due to the lack of other suitable species.

Support for vanilla

Jatropha is grown as a support and shade tree in smallholder vanilla farms in Madagascar and Uganda. The tree stems are pruned while the canopy is left to provide shade. As a result, vanilla plantations report low jatropha seed yields of around 200 kg per ha (Henning, 2004a).

Green manure

Jatropha trees grown from seed develop taproots. Thus, they are able to extract minerals that have leached down through the soil profile and return them to the surface through leaf fall, fruit debris and other organic remains. In this way, jatropha acts as a nutrient pump which helps rehabilitate degraded land.

Plant extracts

Jatropha plant extracts have many uses in traditional societies (Heller, 1996). The dried latex resembles shellac and is used as a marking ink. The leaves and bark are used for dyeing cloth.

Jatropha has medicinal qualities, including a blood coagulating agent and antimicrobial properties that are widely used in traditional medicine and for veterinary use. All parts of the plant are used. Some of these uses that are briefly described below are to some extent anecdotal.

Stem

The latex has a widespread reputation for healing wounds and stopping bleeding, and for curing various skin problems. It is used against pain and the stings of bees and wasps. The fresh stems are used as chewing sticks to strengthen gums and treat gum disease.

Bark and roots

The bark has a purgative effect similar to that of the seeds. In the Philippines, fishermen use the bark to prepare a fish poison. The dried and pulverized root bark is made into poultices and taken internally to expel worms and to treat jaundice. A decoction of the roots is used to treat diarrhoea and gonorrhoea.

Leaves

The leaves also have a purgative effect. Applied to wounds and in decoction, they are used against malaria and to treat hypertension. The leaf sap is used externally to treat haemorrhoids. A hot water extract of the leaves is taken orally to accelerate secretion of milk in women after childbirth. A decoction is used against cough and as an antiseptic following childbirth.

Seeds

The oil-rich seeds and seed oil are used as a purgative and to expel internal parasites. The oil is applied internally and externally to induce abortion, and externally to treat rheumatic conditions and a variety of skin infections. The oil is also an ingredient in hair conditioners.

Fruits and seeds

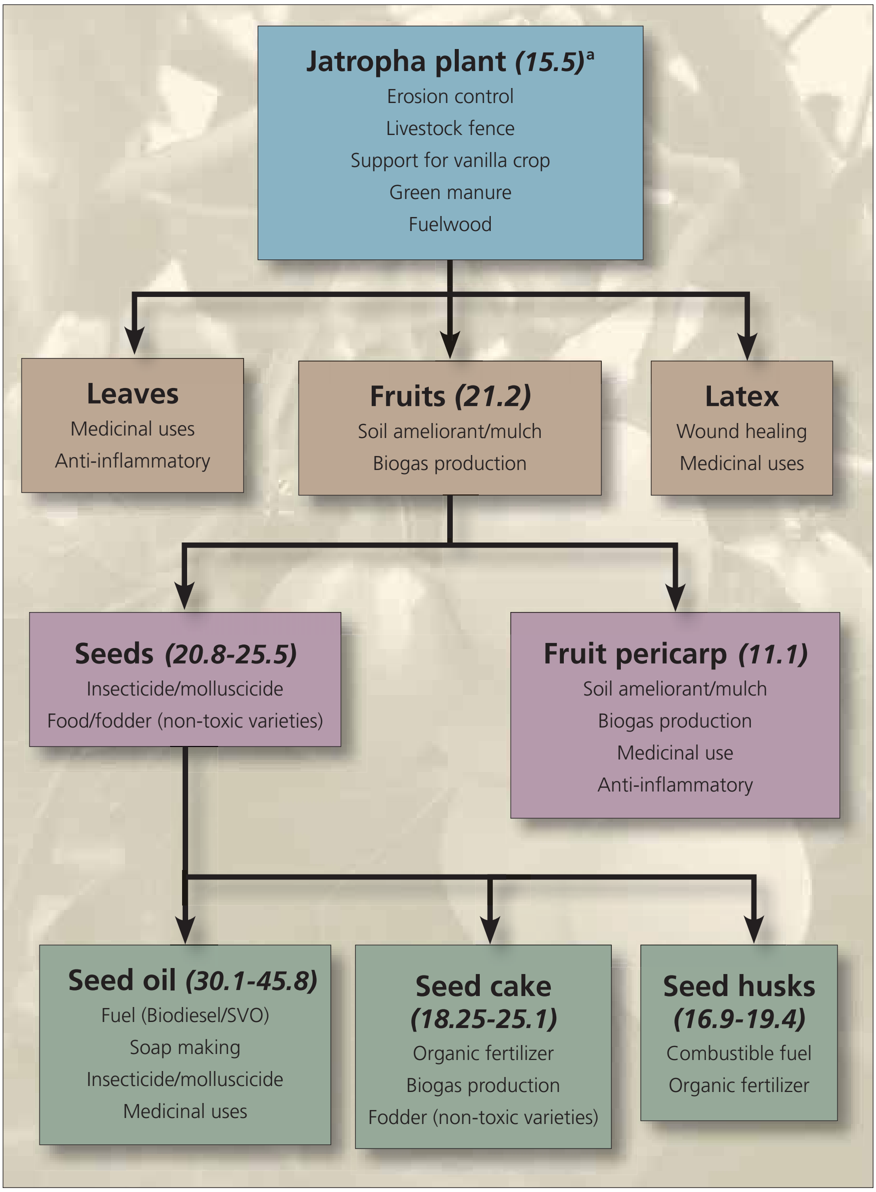
A full account of the uses of the harvested fruit is given in Chapter 4. Besides the current interest in the use of the seed oil for biofuel, it is also used for making soap on a small scale and for illumination. In China, the oil is boiled with iron oxide and used to produce furniture varnish. Extracts of the seed oil have been found effective against a number of crop pests and snail vectors of schistosomiasis.

TOXICITY AND INVASIVENESS

Toxicity

Although the seeds are considered the most toxic part of the plant, all parts of the jatropha plant contain toxins such as phorbol esters, curcins and trypsin inhibitors (Jongschaap, 2007). Varieties commonly found growing in Africa and Asia have seeds that are toxic to humans and animals, whereas some varieties found in Mexico and Central America are known to be non-toxic.

The poisonous and anti-nutrient properties of the seeds are exploited in traditional medicine for de-worming and as a purgative. Just one to three seeds can produce toxic symptoms in humans, mainly those associated with gastro-intestinal irritation. There is acute abdominal pain and a burning sensation in the throat shortly after ingestion of the seeds, followed by nausea, vomiting and diarrhoea. Children are more susceptible. There is



[a] Energy values of the components are given in MJ kg^{-1}.

FIGURE 5: The uses of *Jatropha curcas* and the energy values of its components.

Source: Adapted from Gubitz *et al.* (1999).
Energy values are ranges taken from various sources cited in Jongschaap (2007) and Achten (2008).

no known antidote, but case studies indicate that following accidental ingestion, often by children, full recovery is usual (IPCS, n.d.).

Toxicity is chiefly due to the presence of phorbol esters, as inferred from the fact that non-toxic Mexican jatropha varieties are deficient in these compounds. Phorbol esters are known to be co-carcinogenic, meaning that they are tumour promoting in the presence of other carcinogenic substances. It has been reported that phorbol esters decompose rapidly – within six days – as they are sensitive to light, elevated temperatures and atmospheric oxygen (Rug and Ruppel, 2000, cited Jongschaap, 2007), but there is no supporting data for this. The decomposition of these and other toxic compounds in the field needs further evaluation before insecticide or molluscicide oil extracts can be widely used, or before the widespread application of seed cake as fertilizer, particularly on edible crops, given that there is no information as to whether such compounds are taken up by plants.

Curcin has been described as a major toxic component of jatropha, similar to ricin which is a well known poison. Yet, experiments on mice suggest that curcin is, in fact, innocuous and has a median lethal dose (LD_{50}) some 1000 times that of ricin. Curcin is commonly found in edible plants (King *et al.*, 2009).

For toxic varieties of jatropha, all the products, including the oil, biodiesel and the seed cake, are toxic. Laboratory-scale detoxification of the seed cake to render it usable as a livestock feed is possible, but it is not straightforward and is unlikely to be economically feasible on a small scale.

Mexico has varieties of *Jatropha curcas* that are not poisonous and, in fact, Gubitz (1999) reported that wildlife and livestock feed on the seeds, and that traditional Mexican dishes use the boiled and roasted seeds. Using these varieties in future breeding programmes is the most likely route to non-toxic jatropha products.

Invasiveness

The fact that jatropha can grow and colonize areas that are inhospitable to other plants makes it a potentially invasive species. While some field observers have stated that the plant is not invasive (Henning, 2004a), Australia's Northern Territory and Western Australia have declared it a noxious weed and have biological control programmes in place for its close relative *Jatropha gossypiifolia*. South Africa bans commercial production of *Jatropha curcas* due to these environmental concerns. Brazil, Fiji, Honduras, India, Jamaica, Panama, Puerto Rico and El Salvador classify it as a weed.

The Global Invasive Species Programme (GISP) has developed a list of species being considered as biofuel feedstocks that are potentially invasive. It also has compiled the following recommendations for governments considering development of biofuels (GISP, 2008).

- **Information gathering:** check national noxious weed lists, databases and Web sites for references relevant to the countries where biofuel developments are proposed.
- **Risk assessment:** use formal risk assessment protocols to evaluate the risk of invasion by species in biofuel proposals, with particular attention and support to countries with less experience in addressing biological invasions or screening for impacts on biodiversity.
- **Benefit/cost analysis:** conduct market studies and present business plans that show real benefits for the proposed activities before funds are made available, as there are many known cases of introduced species that have never achieved commercial value and, instead, have become actual or potential problems.
- **Selection of native or low-risk species:** create incentives for the development and use of native and/or non-native species that pose the lowest risks to biodiversity.
- **Risk management:** develop monitoring and contingency plans, such as control in case of escape, in proposals for biofuels, particularly biodiesel. Invasive species that are normally dispersed by animals and other active means must not be used without viable and well-tested control procedures and contingency plan for escapes.
- **Certification/accreditation processes:** evaluate project proposals according to criteria and/or certification schemes for sustainable biofuels development. A number of such processes are underway at the national and international levels.

Pest Risk Analysis (PRA) and Pest Risk Management (PRM) are tools developed by the European and Mediterranean Plant Protection Organization (EMPPO) to "evaluate biological or other scientific and economic evidence to determine whether a pest should be regulated and the strength of any phytosanitary measures to be taken against it."[2] The EMPPO's PRA is part of the International Standard for Phytosanitary Measures (ISPM) on PRA that has been developed in the International Plant Protection Convention (IPPC) framework.

The strengths and weaknesses of jatropha are summarized in Boxes 1 and 2 respectively.

BOX 1. **Jatropha – Strengths**

- Jatropha has the potential, through varietal improvement and good farming practices, for a high level of oil production per unit area in the subhumid tropical and subtropical environments.
- Jatropha grows and is potentially productive in semi-arid areas on degraded and saline soils.
- Jatropha can be used for halting and reversing land degradation.
- Jatropha grows fast, as compared to many other tree-borne oilseeds.
- Jatropha trees remain small, enabling ease of management.
- Jatropha has periodic leaf shedding which facilitates nutrient recycling and dry season irrigated intercropping with short-term crops.
- Jatropha leaves are unpalatable to grazing livestock, making it a good barrier hedge to protect crops.
- Jatropha oil has physical and chemical properties that make it highly suitable for processing into biodiesel.
- Jatropha oil can be used directly in suitable diesel engines, lamps and cooking stoves.
- Jatropha by-products have potential value, such as using seed cake as fertilizer, animal feed (non-toxic varieties) or biogas, and using fruit shells and seed husks for biogas and combustion.
- Jatropha oil has markets other than for fuel, such as the production of soap, medicines and pesticides.
- Jatropha seeds are storable and processing can be delayed, which makes production suited to remote areas.
- Jatropha has attracted investment, mainly from the private sector, into plant breeding, which increases the likelihood of developing jatropha varieties with improved and stable oil yields.

2 See http://www.eppo.org/QUARANTINE/Pest_Risk_Analysis/PRA_intro.htm.

BOX 2. **Jatropha - Weaknesses**

- Jatropha research has not yet identified varieties that are reliably high yielding.
- Jatropha trees vary greatly in yield, oil content and oil quality.
- Jatropha can survive poor growing conditions but, in the absence of sufficient water and nutrients, it has poor yields.
- Jatropha agronomic and production system information is lacking, most importantly for the reliable prediction of yield.
- Jatropha cultivation has potential environmental risks and benefits, which have not been identified sufficiently.
- Jatropha takes 3–5 years to reach economic maturity, which is longer than annual oilseed crops.
- Jatropha yield expectations touted in the popular press are overly optimistic, with high probability that some farmers may well lose interest before improved genotypes and agronomic practices are in place.
- Jatropha toxicity prevents use of the seed cake for livestock feed, which otherwise would add significant value.
- Jatropha toxicity may present a health risk to plantation workers, children and livestock.
- Jatropha harvesting is labour intensive and mechanization is difficult due to the poor synchronicity of fruiting.
- Jatropha is susceptible to pests and diseases when grown as a plantation monocrop, although not more so than other crops.
- Jatropha wood is soft and not good for burning or construction.
- Jatropha is not frost tolerant and cannot tolerate waterlogging.
- Jatropha may act as a host for cassava diseases.
- Jatropha oil is less suited to direct use as a mineral diesel substitute in cool climates due to its viscosity, which is higher than rapeseed oil.
- Jatropha may become a weed problem in certain environments.


Photo: FAIDUTTI

CHAPTER 3

Jatropha cultivation

This chapter brings together available information on the factors required for successful cultivation of jatropha for oil production. It describes climate and soil requirements to guide site selection, followed by information on best crop establishment and management practices. There is a lack of data on oil yield under different conditions, but the section on seed yields summarizes the information that is available.

CLIMATE

Jatropha grows in tropical and sub tropical regions, with cultivation limits at 30ºN and 35ºS. It also grows in lower altitudes of 0-500 metres above sea level (see Figure 6). Jatropha is not sensitive to day length (flowering is independent of latitude) and may flower at any time of the year (Heller, 1996).

It is a succulent shrub that sheds its leaves during the dry season, with deep roots that make it well suited to semi-arid conditions. While jatropha can survive with as little as 250 to 300 mm of annual rainfall, at least 600 mm are needed to flower and set fruit. The optimum rainfall for seed production is considered between 1 000 and 1 500 mm (FACT, 2007), which corresponds to subhumid ecologies. While jatropha has been observed growing with 3 000 mm of rainfall (Foidl, 1996, cited Achten, 2008), higher precipitation is likely to cause fungal attack and restrict root growth in all but the most free-draining soils. *Jatropha curcas* is not found in the more humid parts of its area of origin, Central America and Mexico.

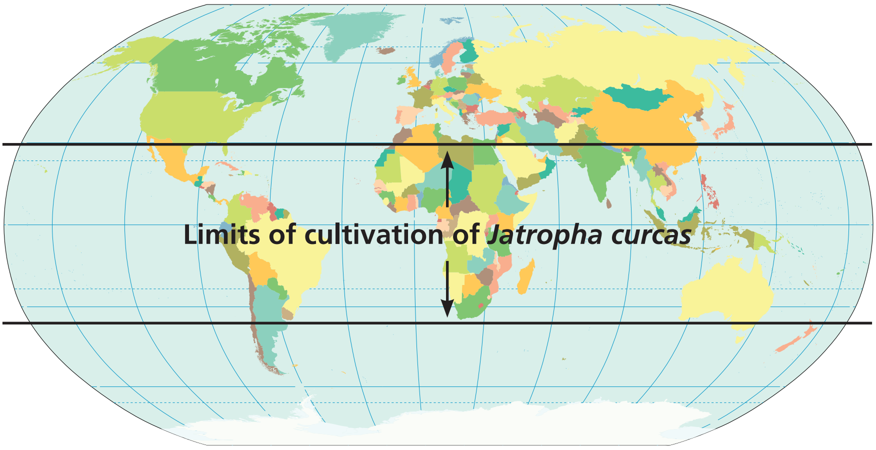


FIGURE 6: Cultivation limits of *Jatropha curcas*

Rainfall induces flowering and, in areas of unimodal rainfall, flowering is continuous throughout most of the year. Optimum temperatures are between 20˚C and 28˚C. Very high temperatures can depress yields (Gour, 2006). Jatropha has been seen to be intolerant of frost. The plant is well adapted to conditions of high light intensity (Baumgaart, 2007, cited Jongschaap, 2007) and is unsuited to growing in shade.

SOILS

The best soils for jatropha are aerated sands and loams of at least 45 cm depth (Gour, 2006). Heavy clay soils are less suitable and should be avoided, particularly where drainage is impaired, as jatropha is intolerant of waterlogged conditions. Ability to grow in alkaline soils has been widely reported, but the soil pH should be within 6.0 to 8.0/8.5 (FACT, 2007). There is evidence from northwest India that jatropha is tolerant of saline irrigation water, although yield under these conditions is not documented (Dagar *et al*., 2006).

Jatropha is known for its ability to survive in very poor dry soils in conditions considered marginal for agriculture, and can even root into rock crevices. However, survival ability does not mean that high productivity can be obtained from jatropha under marginal agricultural environments.

Being a perennial plant in seasonally dry climates, soil health management under jatropha production would benefit from conservation agriculture practices. This would result in minimum soil disturbance, an organic mulch cover on the soil surface and legume cover crops as intercrops.

PROPAGATION AND CROP ESTABLISHMENT

The selection of planting material should be from cuttings or seed that have proven, over several seasons, to have high yield and seed oil content under the same irrigation and fertilization conditions that are proposed for the new plantation. Seed from high-yielding jatropha plants is not generally available, due to the fact that the out-crossing seed selected from productive plants may or may not result in high-yielding and high-quality plants. Trees capable of producing more than 2 tonnes of dry seed per ha with 30 percent seed oil content should be selected as source material (Achten, 2008). Opinion is divided on the choice of seed or cuttings. Heller (1996) considers the ability of seedlings to develop taproots to be important, while R.K Henning (personal communication, 18 February 2009) sees cuttings as a better option because it enables production of the best-yielding clones. The difficulty of obtaining sufficient cuttings is a consideration. Nursery-raised seedlings using essentially wild varieties probably account for the majority of jatropha planting to date.

Heller (1996) found that cuttings of at least 30 mm diameter gave earlier and higher initial yields than plants raised from seed, although little or no yield difference was seen for later harvests. However, cuttings taken from carefully chosen plants with higher yield potential would probably continue to out yield seed raised plants. Raising plantlets from tissue culture is being researched and protocols have been developed but, as it is a latex-producing plant, the procedure is not straightforward. There are no reports of tissue culture of jatropha being applied on a large scale.

Heller (1996) found that nursery-raised plants from seed and cuttings and direct planting of cuttings have a higher survival rate (more than 80 percent) than seeding directly in the field (less than 50 percent). A summary of the merits and demerits of different propagation methods is given in Table 1 (see page 31).

Vegetative propagation using cuttings

The advantage of using cuttings is their genetic uniformity, rapid establishment and early yield. The disadvantage is the scarcity of material, and the cost of harvesting, preparation, transport and planting of the woody stems, compared to seeds. A further disadvantage is that cuttings do not produce a taproot, meaning there is less capacity for the plant to reach soil water and nutrient reserves with correspondingly lower potential yields, although the effect of this, for different environments, has not yet been determined. The absence of a taproot makes for less stability on exposed windy sites, and cuttings compete more for water and nutrients with intercrops. Seedling-raised plants would be a better choice in this situation and for agroforestry systems. Poorer longevity may be expected for plantations established using cuttings (Heller, 1996).

The survival rate improves with the length and thickness of the cutting. Recommendations for cutting length vary from 25 to 120 cm. Cuttings taken from the middle or lower parts of year-old branches show greater survival rates (Kaushik and Kumar, 2006, cited Achten, 2008). These can be inserted 10–20 cm into the soil in shaded nursery beds for bare root transplanting, planted into polyethylene bags or planted directly into their final planting positions. Rooting takes two to three months, meaning that cuttings should be planted ahead of the rainy season, so that rooting will coincide with the start of the rains. Experiments by Narin-Sombunsan and Stienswat (1983, cited Heller, 1996) showed that application of the rooting hormone IBA did not promote root formation, whereas rooting was increased with aerated, well-drained rooting media. Mini-cuttings may be prepared by laying cuttings horizontally in rooting media and, when the nodes have sprouted and produced adventitious roots, cutting the stems at the internodes and planting them into polyethylene bags for further growth in the nursery before being planted out (Gour, 2006).

Propagation from seed

Pre-cultivation in nurseries, sown in either nursery beds or containers (see Plate 9), enables better germination and survival of seedlings through control over moisture, shade, soil, weeds, pests and diseases. Seeds should be sown three months before the start of the rains in polyethylene bags or tubes. The bags should be long enough to avoid unduly restricting taproot growth.

The use of specifically designed tree propagation cells (e.g. Rootrainers) that have internal vertical ribs and air-pruning holes would be beneficial.

TABLE 1: **ALTERNATIVE PROPAGATION METHODS**

PARENT MATERIAL	ADVANTAGES	DISADVANTAGES
Seed – sown directly in the field	Cheapest method. Good taproot development.	Lower survival rate of seedlings. Least successful method of propagation. Poor uniformity of growth. Variable productivity of the progeny. More weeding required in the field.
Seed – nursery raised in polybags	Control of seedling environment. Fewer losses. More uniform plants.	Higher costs than direct seeding. Variable productivity of the progeny. Seedling taproot development may be impaired by the polybag.
Seed – nursery raised in seedbed	As above. No restriction of taproot. Lower transport costs.	Higher costs than direct seeding. Variable productivity. Higher losses at planting out of bare root seedlings.
Vegetative cuttings – planted directly in the field	Clones give more uniform productivity and potentially higher yields per ha. Yields sooner than seed-raised plants.	Sufficient cuttings of good plants may be difficult and costly to source. Lack of a taproot means poor soil anchorage, less capacity to extract water and nutrients, less suited to intercropping. Shorter productive life of the plantation. Larger cuttings needed to ensure survival.
Vegetative cuttings – nursery raised in polybags	As above. Fewer losses and more uniform plants. Mini-cuttings may be used where parent material is scarce.	As above. Higher costs than planting cuttings directly.
Vegetative cuttings – nursery raised in seedbed	As above. Lower transport costs from nursery to field.	As above. Higher losses when planted out.
Tissue culture	Clonal. Uniform productivity. Develops taproot. Rapid multiplication of new plants.	High cost. Newly developed protocols not yet commercially viable.

PLATE 9: Jatropha seed nursery, Tanzania.

The bags or cells should be filled with free-draining growing media containing organic matter (such as 1:1:1 sand-soil-manure or 1:1:2 sand-soil-compost) and well watered prior to sowing (Achten, 2008). Seeds should be taken from mature yellow or brown fruits and graded. Only the largest should be selected for sowing and any that do not sink in water should be discarded. Pre-treatment to soften or break the seed coat will enhance germination. In tests, pre-soaking in cow dung slurry for 12 hours gave 96 percent germination compared to soaking in cold water or nicking the seed coat which gave around 72 percent (Achten *et al.*, 2008). One seed per bag should be placed at 2–4 cm depth with the caruncle oriented downwards (Srimathi and Paramathma, 2006). The seeds should be kept well watered and will then germinate within 6–15 days. Seedlings may be planted out after two to three months, after reaching a height of 30–40 cm and before taproot development becomes overly restricted. Nursery shade should be gradually removed for hardening off the plants before they are transplanted to the field.

Sowing into nursery beds with suitably prepared free-draining and fertilized soil is a cheaper option that avoids expenditure on bags and reduces transport and labour cost at transplanting. The downside is the greater care needed to avoid damaging the roots and preventing the plants from drying out during the lifting and transplanting operation.

Direct seeding in the field should take place at the beginning of the rainy season when the rain is assured. Timing is crucial for success. Seed stored and dried for at least one month should be used to overcome seed dormancy. The seeds should be planted 4–6 cm deep, with two per station, and later thinned to one. Since 1 300 seeds weigh approximately 1 kg, the seed rate for planting one ha (at 2 500 plants per ha) is about 4 kg (R.K. Henning, personal communication, 10 May 2009).

Planting

Jatropha is planted at densities ranging from 1 100 to 2 500 plants per ha. Yield per tree is likely to increase with wider spacing but with a decline in yield per ha (Achten, 2008). Spacing decisions should be based on the environment, i.e. how it affects competition among trees for water, light and nutrients. Semi-arid, low-input systems should use wider spacing such as 3.0 x 2.0, 3.0 x 2.5 or 3.0 x 3.0 metres. Alternate planting in succeeding rows will minimize mutual shading. In addition, consideration should be given to access. At least 2.5 m between trees allows easier passage for fruit pickers, while a 5-metre alley at every fourth row facilitates access by carts.

Planting holes of 30–45 cm wide and deep should be prepared and organic matter incorporated before planting. An insecticide may be included as a precaution against termites. The seedlings may require irrigation for the first two to three months after planting.

Where jatropha is being planted as a living hedge, cuttings of 60–120 cm length should be inserted between 5 and 25 cm apart and 20 cm into the ground. This should be done two to three months before the onset of the rainy season.

Intercropping

While intercropping during the first five years of a jatropha plantation is common practice, there have been few studies on intercrop yields, plant spacing or optimal management practices. The same applies to permanent

Photo: WANI - ICRISAT

PLATE 10: Jatropha intercropped with pigeon pea.

intercropping systems and agroforestry. Plate 10 shows the intercropping of young jatropha trees in India.

Trials in Uttar Pradesh, India, found that groundnuts could be grown successfully between lines of jatropha trees spaced 3.0 metres apart and pruned down to 65 cm. The groundnuts were planted in the dry season with limited irrigation, when there was no leaf cover from the jatropha. It was found that this system helped with weed control of the plantation and that the growth of intercropped jatropha was better than the non-intercropped control (Singh *et al.*, 2007).

Crop maintenance

Once established, growth is rapid. The leading shoot may reach 1 m within five months, with all vegetative growth during the rainy season. Trees typically bear their first fruit following flowering in the second rainy season. Before the ground is shaded by the developing leaf canopy, it is important to control competing weeds regularly. The cut weeds may be left as surface mulch. In semi-arid regions, digging contour trenches and basins around individual plants aids water entrapment and infiltration.

Pruning during the dry or dormant season is important to increase branching and the number of tip-borne inflorescences, as well as to form a wide low-growing tree that is easier to harvest. The stem and branches may be pinched out at six months to encourage the development of laterals and the main stem cut back to 30–45 cm. The branch tips are pruned again at the end of the first year. In the second and subsequent years, branches are pruned by removing around two-thirds of their length. After ten years, it is recommended to cut trees down to 45 cm stumps to improve yields. Re-growth is rapid and trees will start bearing again within a year (Gour, 2006).

Flowers require the presence of pollinating insects. Thus, it may be beneficial to place hives for honey bees in the proximity.

PLANT NUTRITION

Jatropha is often described as having a low nutrient requirement because it is adapted to growing in poor soils. However, growing a productive crop requires correct fertilization and adequate rainfall or irrigation. Equally, high levels of fertilizer and excessive irrigation can induce high total biomass production at the expense of seed yield. Unfortunately, there is insufficient data on response to fertilizer under different growing conditions for it to be possible to make specific recommendations for optimal crop nutrition.

On wasteland in India, Ghosh *et al.* (2007) found that 3.0 tonnes per ha of jatropha seed cake (also known as "press" cake), containing 3.2 percent N, 1.2 percent P_2O_5 and 1.4 percent K_2O, increased yields significantly when applied to young plants – by +120 percent and +93 percent at two different planting densities. A trial at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India showed increasing yield with fertilization to an optimum level (T3), but that over-application depressed yields (see Table 2).

The optimum levels of inorganic fertilizers have been seen to vary with the age of the tree (Achten, 2008). Site-specific fertilizer trials need to be established for trees of different ages and over a number of seasons.

An analysis of the nutrient value of harvested fruit indicates the application rate of nutrients required to maintain soil fertility levels, assuming all other biomass is retained in the field. From the nutrient composition calculated by Jongschaap *et al.* (2007), the fruit equivalent of

TABLE 2: **EFFECT OF FERTILIZER LEVELS ON YIELD PARAMETERS OF JATROPHA CURCAS AT ICRISAT, THREE YEARS AFTER PLANTING (INDIA)**

	TREATMENTS (GRAMS PER PLANT)				
	T1	T2	T3	T4	T5
Pods/plant	97.1	90.1	131.4	45.9	53.6
Pod weight (g)	350.9	248.7	390.8	130.7	148.9
Seeds/plant	247	210	341	131	133
Seed weight/plant (g)	168	143	233	83	87
Threshing%	48	57.4	59.5	63.4	58.3
100 seed weight (g)	68	67.8	68	63.1	65.2

T1=50 g Urea + 38 g SSP; T2= 50 g Urea + 76 g SSP; T3= 100 g Urea +38 g SSP; T4= 100 g Urea + 76 g SSP and T5 = Control

Source: Wani *et al.* (2008).

1.0 tonne of dry seed per ha removes 14.3–34.3 kg of N, 0.7–7.0 kg of P, and 14.3–31.6 kg of K per ha.

Mycorrhyzal soil fungi are generally known to improve a plant's ability to absorb mineral nutrients and water from the soil, and to increase drought and disease resistance. The Energy and Resources Institute (TERI) in India has developed mycorrhyzal inoculations for jatropha that improve germination and give earlier fruiting and higher yields. Sharma (2007, cited Jongschaap, 2007) found increased uptake of P and micro-nutrients. In Brazil, studies on mycorrhyzal inoculation of jatropha are also showing promise in improving uptake of P and K (Carvalho, 2007, cited Parsons, 2008).

WATER REQUIREMENTS

There is little quantitative data available on the water needs, water productivity and water-use efficiency of jatropha. It is believed that optimal rainfall is between 1 000 and 1 500 mm (FACT, 2007). On-station trials by ICRISAT confirm this range. Table 3 shows the data for water use over two years.

TABLE 3: **WATER USE OF JATROPHA AT ICRISAT (INDIA)**

ITEM	2006	2007
Rainfall (mm)	895	712
ET Jatropha (mm) – No moisture stress	1354	1352
ET Jatropha (mm) – Actual conditions	777	573
Rainfall contribution to Jatropha ET (%)	87	80
ET actual relative to non-stressed (%)	57	42

Source: Wani *et al*. (2008).

Jatropha shows a flowering response to rainfall. After short (one month) periods of drought, rain will induce flowering. Thus, the cycle of flowering can be manipulated with irrigation (FACT, 2007). However vegetative growth can be excessive at the expense of seed production if too much water is applied, for example with continuous drip irrigation.

PESTS AND DISEASES

It is popularly reported that pests and diseases do not pose a significant threat to jatropha, due to the insecticidal and toxic characteristics of all parts of the plant. Observations of free-standing older trees would appear to confirm this, but incidence of pests and diseases is widely reported under plantation monoculture, and may be of economic significance. Observed diseases, such as collar rot, leaf spots, root rot and damping-off, may be controlled with a combination of cultural techniques (for example, avoiding waterlogged conditions) and fungicides.

The shield-backed or scutellera bug (Plate 11), regarded as a key pest of plantation stands of jatropha in Nicaragua (*Pachycoris klugii*) and India (*Scutellera nobilis*), causes flower fall, fruit abortion and seed malformation. Other serious pests include the larvae of the moth *Pempelia morosalis* which damages the flowers and young fruits, the bark-eating borer *Indarbela quadrinotata*, the blister miner *Stomphastis thraustica*, the semi-looper *Achaea janata*, and the flower beetle


Photo: ICRISAT

PLATE 11: *Scutellera nobilis.*

Oxycetonia versicolor. Termites may damage young plants (see Plate 12). Carefully and judiciously adding an insecticide to the planting pit may be advisable if problems are endemic.

Some biological pest control measures are known. For example, in Nicaragua, *Pseudotelenomus pachycoris* have been found to be effective egg parasitoids of *Pachycoris klugii* and, in India, the dipteran parasitoid of *Pempelia* also offers promise. Attention to increasing resistance to pests and diseases will be needed in jatropha varietal improvement programmes.

Jatropha multifida is a known host of African cassava mosaic virus as well as a possible source of transmission of the cassava super-elongation disease (*Sphaceloma manihoticola*) (Achten, 2008). This indicates that, as a related species, *Jatropha curcas* probably should not be grown in association with this crop.


Photo: HENNING

PLATE 12: Termite damage on young tree, Tanzania.

SEED YIELDS

Since systematic recording of yields started only relatively recently, it is important to note that there is little data available for seed yields from mature stands of jatropha. Earlier reported yields used largely inconsistent data, and claims of high yields were probably due to extrapolation of measurements taken from single, high-yielding elderly trees (Jongschaap *et al*., 2007). Individual tree yields are reported to range from 0.2 to 2.0 kg of seed annually (Francis, 2005).

On an area basis, Openshaw (2000) reports seed yields between 0.4 to 12 tonnes per ha, and Heller (1996) reports yields between 0.1 and 8.0 tonnes per ha. Mostly, these yield figures are accompanied by little or no information on genetic provenance, age, propagation method, pruning, rainfall, tree spacing, soil type or soil fertility.

Heller (1996) and Tewari (2007) suggest that production in semi-arid areas may be around 2.0–3.0 tonnes per ha, though it appears likely that lower average yields are being realized in these sub-optimal conditions.

Photo: MESSEMAKER

PLATE 13: Jatropha fruits at different stages of maturity.

Potential yields for jatropha in semi-arid conditions in Andhra Pradesh, India, are forecast at 1.0 tonne per ha (Wani *et al.*, 2008). Furthermore, during a 17-year period, jatropha growers at Nashik, India, averaged yields of less than 1.25 tonnes per ha (Ghokale, 2008). On the other hand, with good soil, higher rainfall and optimal management practices, there are reported yields of 5.0 (Achten, 2008), and 6.0–7.0 tonnes per ha (FACT, 2007). Jongschaap (2007) calculated a theoretical potential seed yield of 7.8 tonnes per ha under optimal conditions.

Jatropha shows a high variability in yield among individual trees, which is a characteristic of the trees in cultivation being essentially composed of wild varieties. The annual yield variation of 19 trees, shown in Figure 7, range from 0 to 850 grams of dry seed per tree. Clearly, the greatest prospect for yield improvement lies with improving the germplasm.

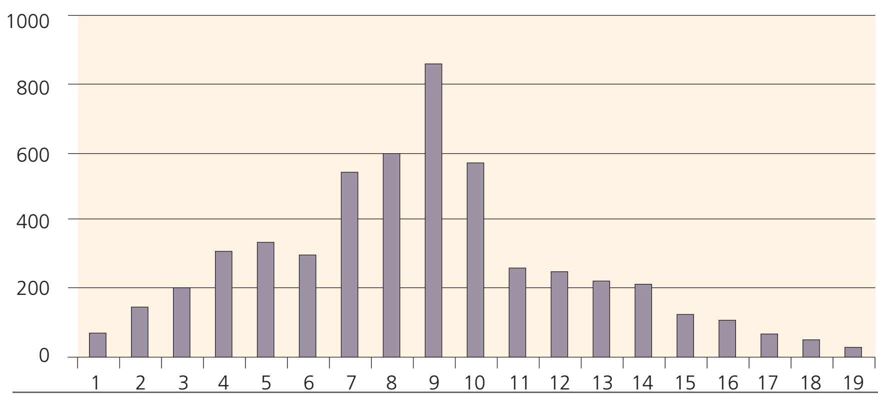


FIGURE 7: Jatropha seed yield for 19 individuals (grams per year) averaged over four years, on poor soil and with no inputs.

Source: Henning (2008).

The economic life of a jatropha plantation reportedly ranges from 30 to 50 years, but there is no evidence to substantiate this. However, individual trees are known to live well in excess of 50 years.

CHAPTER 4

Seed harvest, processing and uses of jatropha

The oil content of jatropha seed can range from 18.4–42.3 percent (Heller, 1996) but generally lies in the range of 30–35 percent. The oil is almost all stored in the seed kernel, which has an oil content of around 50–55 percent (Jongschaap, 2007). This compares well to groundnut kernel (42 percent), rape seed (37 percent), soybean seed (14 percent) and sunflower seed (32 percent).

Photo: MESSEMAKER

PLATE 14: Sun-drying jatropha seed, Tanzania.

The seed kernel contains predominantly crude fat (oil) and protein, while the seed coat contains mainly fibre. The products of the harvested jatropha fruits and their fractions by weight are shown in Figure 8. The fruit shell describes the fruit pericarp, while the seed consists of the inner kernel and the outer husk or seed coat.

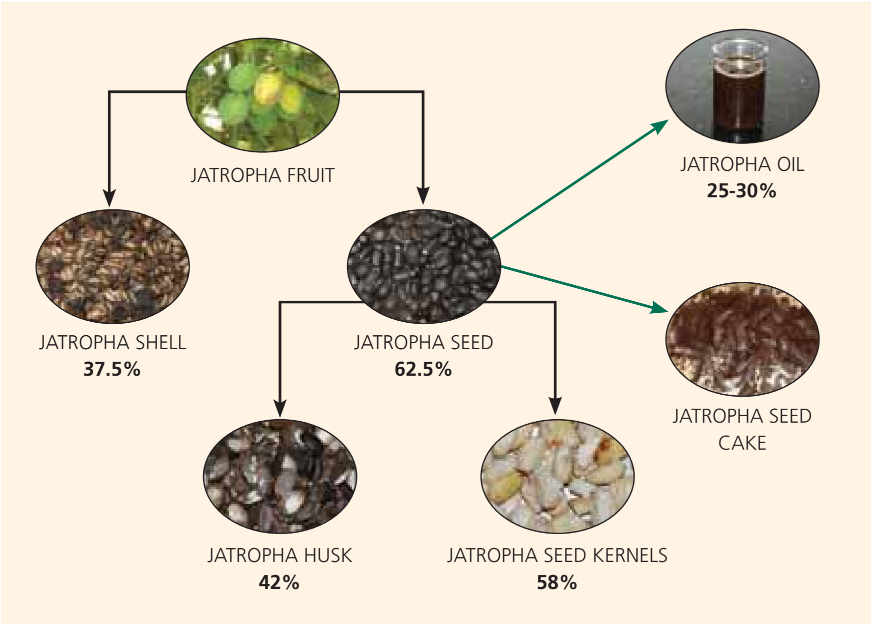


FIGURE 8: **Composition of jatropha fruit.**

Source: Abreu (2008).

HARVESTING

Seeds are ready for harvesting around 90 days after flowering when the fruits have changed from green to yellow-brown. In wetter climates, fruiting is continuous throughout the year, while the harvest may be confined to two months in semi-arid regions. Even then, the fruits do not ripen together, requiring weekly picking and making the harvest labour intensive and difficult to mechanize.

The yellow and brown fruits are harvested by beating the branches with sticks to knock them to the ground, or by hand picking. The fruits are dried and the seeds removed from the fruit shells by hand, by crushing with a wooden board or by using a mechanical decorticator. Work rates for harvesting are given by Henning (2008a) as 24 kg per workday while India's National Oilseeds and Vegetable Oils Development Board (NOVOD) gives a rate of 50 kg of seed per workday (NOVOD, 2007). The seeds are shade dried for sowing but dried in the sun for oil production to reduce moisture content to around 6–10 percent. If kept dry and ventilated, the seeds may be stored for up to 12 months without loss of germination or oil content, although there may be losses to pests in storage.

OIL EXTRACTION

Traditional oil extraction methods are highly labour intensive, requiring some 12 hours to produce one litre of oil. The process requires roasting the seed kernels, pounding them to a paste, adding water and boiling, and then separating the oil by skimming and filtering.

The Bielenberg ram press (shown in Plate 15) is a hand-operated expeller designed for construction and repair by small and simply equipped workshops. It has a low work rate – one litre of oil produced per hour – and therefore is only suited to small-scale or demonstration use (Henning, 2004a).

Photo: HENNING

Photo: HENNING

PLATE 15 (LEFT): **Bielenberg ram press, Tanzania.**

PLATE 16 (ABOVE): **Sayari oil expeller driven by Lister-type diesel engine, Tanzania.**

A hand-operated screw press is more efficient, but maintenance and repairs become more problematic. Engine-driven expellers can have work rates of 55 litres per hour (Henning, 2008b), with about 10 percent of the oil produced required to fuel the diesel engine that powers the press (see Plate 16). The Sayari expeller, manufactured in Tanzania, has a work rate of 15–33 litres per hour with a 4–5 kW engine and is capable of extracting 15 litres of oil from 75 kg of seed.

To improve the oil extraction efficiency of the hand expellers, the seeds should be heated by leaving them in the sun or by roasting them gently for ten minutes. For small-scale production, it is common practice to feed the expeller with whole seeds. In large processing plants, the husk, which constitutes 40 percent of the seed weight, can be removed first and used as a fuel, for burning or as a biogas feedstock.

Small-scale, hand-operated expellers can extract 1 litre of oil for every 5.0 to 5.5 kg of seed. Jongschaap (2007) gives a range of 19–22 percent of oil from the dry whole seed and 30 percent of the seed kernel, by weight. Hand presses are relatively inefficient, extracting only about 60 percent of the available seed oil. Engine-driven screw presses can extract 75–80 percent of the available oil, producing 1 litre of jatropha oil from every 4 kg of dried seed (Henning, 2000, cited Achten *et al.*, 2008). Pre-heating, repeat pressings and solvent extraction further increase the extraction rate, but are more suited to large-scale processing.

To improve storability, solids remaining in the oil must be removed, either by sedimentation, centrifuge or filtration. A plate filter is commonly used in biodiesel processing plants (see Plate 17). Sedimentation is the normal method for small-scale oil production. It is particularly important to clean the filter press thoroughly and remove all traces of the toxic jatropha oil before using it to extract edible oils.

Photo: BRITTAINE

PLATE 17: **Plate filter in a biodiesel production plant, India.**

PROPERTIES OF JATROPHA OIL

Oil quality and consistency are important for producing biodiesel. The physical and chemical content of jatropha oil can be extremely variable. Oil characteristics appear to be influenced by environment and genetic interaction, as are seed size, weight and oil content. The maturity of the fruits also can affect the fatty acid composition of the oil, and processing and storage further affect oil quality (Raina and Gaikwad, 1987, cited Achten *et al.*, 2008).

Oil quality is also important when producing jatropha oil for direct use as a fuel. More investigation is necessary to determine what oil quality can be attained reasonably in representative rural conditions. In general, it is necessary to ensure low contamination of the oil, low acid value, high oxidation stability and low contents of phosphorus, ash and water.

Crude jatropha oil is relatively viscous, more so than rapeseed. It is characteristically low in free fatty acids, which improves its storability, though its high unsaturated oleic and linoleic acids make it prone to oxidation in storage. The presence of unsaturated fatty acids (high iodine value) allows it to remain fluid at lower temperatures. Jatropha oil also has a high cetane (ignition quality) rating. The low sulphur content indicates less harmful sulphur dioxide (SO_2) exhaust emissions when the oil is used as a fuel. These characteristics make the oil highly suitable for producing biodiesel. Table 4 compares the physical properties of jatropha oil and diesel oil.

TABLE 4: **COMPARISON OF THE CHARACTERISTICS OF FOSSIL DIESEL OIL COMPARED TO PURE JATROPHA OIL**

	DIESEL OIL	OIL OF *JATROPHA CURCAS* SEEDS
Density kg/l (15/40 °C)	0.84 – 0.85	0.91 – 0.92
Cold solidifying point (°C)	-14.0	2.0
Flash point (°C)	80	110 – 240
Cetane number	47.8	51.0
Sulphur (%)	1.0 – 1.2	0.13

Source: GTZ (2006)

USES OF JATROPHA OIL

Jatropha oil as a biodiesel feedstock

The production of jatropha biodiesel is a chemical process whereby the oil molecules (triglycerides) are cut to pieces and connected to methanol molecules to form the jatropha methyl ester. An alkali – normally sodium hydroxide (caustic soda) – is needed to catalyze the reaction. Glycerine (glycerol) is formed as a side product. Methanol is normally used as the alcohol for reasons of cost and technical efficiencies. This process is summarized in Figure 9.

Sodium hydroxide is dissolved in methanol to form sodium methoxide, which is then mixed with jatropha oil. The glycerine separates out and is drained off. The raw biodiesel is then washed with water to remove any remaining methanol and impurities. Typical proportions used in the reaction are:

Inputs:

- 100 units of jatropha oil
- 10 to 15 units of methanol
- 0.5 to 2 units of sodium hydroxide catalyst

Outputs:

- 100 units of biodiesel
- 10 to 15 units of glycerine

FIGURE 9: Chemical reaction for converting jatropha oil to biodiesel.

$$\text{Triglyceride (jatropha oil)} + \text{Methanol} \xrightarrow[\text{Sodium hydroxide}]{} \text{Methyl ester (biodiesel)} + \text{Glycerine}$$

Biodiesel may be used as partial blends (e.g. 5 percent biodiesel or B5) with mineral diesel or as complete replacements (B100) for mineral diesel. In general, B100 fuels require engine modification due to the different characteristics of biodiesel and mineral diesel. Van Gerpen *et al.* (2007) note specifically that solvent action may block the fuel system with dislodged residues, damage the hoses and seals in the fuel system, or cause cold filter plugging, poorer performance due to the lower heating value of biodiesel, some dilution of the engine lubricating oil, and deposit build-up on injectors and in combustion chambers.

It is generally accepted by engine manufacturers that blends of up to 5 percent biodiesel should cause no engine compatibility problems. Higher blends than this may void manufacturers' warranties. Jatropha biodiesel has proven to conform to the required European and USA quality standards. Table 5 shows that jatropha biodiesel generally exceeds the European standard.

For every 1 litre of biodiesel, 79 millilitres of glycerine are produced, which is equivalent to around 10 percent by weight. The raw glycerine contains methanol, the sodium hydroxide catalyst and other contaminants, and must be purified to create a saleable product. Traditional low-volume/high-value uses for glycerine are in the cosmetic, pharmaceutical and confectionary industries, but new applications are being sought as production shifts to high volume/low value. Glycerine is used in the production of fuel, plastics and antifreeze.

The production of biodiesel requires expertise, equipment and the handling of large quantities of dangerous chemicals (methanol is toxic and sodium hydroxide is highly corrosive). It is not a technology suited to resource-poor communities in developing countries.

TABLE 5: **CHARACTERISTICS OF JATROPHA BIODIESEL COMPARED TO EUROPEAN SPECIFICATIONS**

CHARACTERISTIC	JATROPHA BIODIESEL	EUROPEAN STANDARD	REMARKS[a]
Density (g cm^{-3} at 20°C)	0.87	0.86 – 0.900	+
Flash point (°C)	191	>101	+
Cetane no. (ISO 5165)	57 – 62	>51	+++
Viscosity mm^2/s at 40°C	4.20	3.5 – 5.0	+
Net cal. val. (MJ/L)	34.4	-	-
Iodine No.	95 – 106	<120	+
Sulphated ash	0.014	<0.02	+
Carbon residue	0.025	<0.3	++

[a] + indicates that jatropha performs better than the European standard.

Source: Francis *et al.* (2005).

Pure jatropha oil

Jatropha oil may be used directly in some diesel engines, without converting it into biodiesel. The main problem is that jatropha oil has higher viscosity than mineral diesel, although this is less of a problem when used in the higher temperature environment of tropical countries. The following are the available options for using jatropha oil in diesel engines.

- **Indirect-injection engines:** Some indirect-injection (IDI) diesel engines of older design, such as the Lister single cylinder engines, can use jatropha oil without any problems. These engines, made in India, require no modification other than an appropriate fuel filter. In fact the higher oxygen content of the jatropha oil can deliver greater power under maximum load than diesel. These engines can be run on jatropha oil, biodiesel, mineral diesel or a blend.
- **Two-tank system:** The power unit may be modified to a two-tank system. This is effectively a flex-fuel power unit which may run on mineral diesel, any blend of biodiesel or on vegetable oil. The problem of cold starting with the more viscous vegetable oil is avoided by starting and stopping the engine using diesel or biodiesel and then switching tanks to run on the oil when it reaches the critical temperature. Detergents in the mineral diesel prevent the build-up of carbon deposits and gums in the pump and on the fuel injectors. Switching between fuels may be manual or automatic.
- **Single-tank vegetable oil system:** A single-tank vegetable oil system uses fuel injectors capable of delivering higher pressures to overcome the high oil viscosity, stronger glow plugs, a fuel pre-heater and a modified fuel filter.

A number of manufacturers produce engines that use these single and two-tank technologies. The addition of proprietary organic solvents to the vegetable oil is sometimes recommended to improve engine performance. The long-term viability of these systems in terms of engine performance and reliability remains to be fully assessed.

The oil must be of a quality satisfactory for long-term performance of engines run on jatropha oil. Although fresh jatropha oil is low in free fatty acids, it must be stored in closed, dry, cool conditions. The presence of particles and phosphorous in the oil can block filters and cause engine wear. Phosphorous content is lower when the oil is pressed at temperatures less than 60°C.

The oil should be well filtered (five microns) to remove contaminants and its water content kept as low as possible to reduce corrosion and wear in the engine, and avoid build up of microbial growth in the fuel delivery system (de Jongh and Adriaans, 2007). Jatropha oil has been found adequate for use as a crankcase engine lubricant in Lister-type diesel engines.

Cooking fuel

There are clear advantages to using plant oil instead of traditional biomass for cooking. These include the health benefits from reduced smoke inhalation, and environmental benefits from avoiding the loss of forest cover and lower harmful GHG emissions, particularly carbon monoxide and nitrogen oxides.

The high viscosity of jatropha oil compared to kerosene presents a problem that necessitates a specially designed stove. There are two basic designs – one uses pressure to atomize the oil and one uses a wick.

- **Pressure stove** is difficult to use. Designed by the University of Hohenheim, it requires pre-heating with alcohol or kerosene and frequent cleaning to remove carbon deposits.

Photo: HENNING

Photo: HENNING

PLATE 18 (ABOVE): Kakute stove.

PLATE 19 (RIGHT): Binga oil lamp.

- **Wick stove** requires further improvement because the viscous oil does not rise up the wick as easily as kerosene and the oil does not vaporize, which means that it leaves carbon deposits on the wick as it burns. An example of this type is the Kakute stove shown on page 49.

Lighting fuel

The problem of jatropha oil's high viscosity also applies to lamp design. A lamp with a floating wick offers one solution to the oil's poor capillary action. This allows the wick to be kept as short as possible, with the flame just above the oil. The Binga oil lamp, shown in Plate 19, uses this system. It requires periodic cleaning of the wick to remove carbon deposits. Ordinary kerosene lamps may be modified to lower the wick, but the oil level has to be maintained at a constant level and the wick again needs frequent cleaning. There is anecdotal evidence that using a jatropha oil lamp deters mosquitoes.

Soap making

Jatropha soap is made by adding a solution of sodium hydroxide (caustic soda) to jatropha oil. This simple technology has turned soap making into a viable small-scale rural enterprise appropriate to many rural areas of developing countries. Jatropha soap is valued as a medicinal soap for treating skin ailments. On the one hand, making jatropha soap can be highly profitable, with 4.7 kg of soap produced from 13 litres of jatropha oil in only five hours (Henning, 2004b). On the other hand, Wiesenhütter (2003) finds that locally produced jatropha soap has limited commercial potential, as the quality is poor in comparison to imported soaps.

Other uses for the oil

Jatropha oil has molluscicidal properties against the vector snails of the *Schistosoma* parasite that causes bilharzia. The emulsified oil has been found to be an effective insecticide against weevil pests and houseflies, and an oil extract has been found to control cotton bollworm and sorghum stem borers (Gubitz, 1999). Shanker and Dhyani (2006, cited Achten *et al.*, 2008) describe the use of oil extracts as an insecticide, molluscicide, fungicide and nematicide. These potential uses have yet to be commercialized.

As previously mentioned, the oil is widely used as a purgative in traditional medicine. It also is used to treat various skin diseases and rheumatism (Heller, 1996).

PROPERTIES AND USES OF THE SEED CAKE

Once the oil is extracted, about 50 percent of the original seed weight remains as seed cake residue, mainly in the form of protein and carbohydrates. The amount of oil left in the seed cake depends on the extraction process. There are trade-offs for the seed cake. It may be used as fertilizer, fuel or, if it is detoxified or if non-toxic varieties are used, it can be used as animal fodder. However, it is significant that not returning the seed cake to the plantation as fertilizer reduces the utility of jatropha in improving degraded land.

Livestock feed

Jatropha seed cake is high in protein – 58.1 percent by weight compared to soy meal's 48 percent – and would be a valuable livestock protein feed supplement if it were not for its toxicity. Currently, removal of toxins is not commercially viable. Using non-toxic varieties from Mexico could make greater use of this potentially valuable by-product, but even these varieties may need treatment to avoid sub-clinical problems that could arise with long-term feeding of jatropha seed cake to livestock (Makkar and Becker, 1997).

Organic fertilizer

Jatropha seed cake makes an excellent organic fertilizer with a high nitrogen content similar to, or better than, chicken manure. Its macronutrient composition is shown in Table 6.

TABLE 6: **MACRONUTRIENT CONTENT OF JATROPHA SEED CAKE**

N%	P%	K%	Ca%	Mg%	SOURCE
4.4 – 6.5	2.1 – 3.0	0.9 – 1.7	0.6 – 0.7	1.3 – 1.4	Achten *et al.* (2008)
3.0 – 4.5	0.65 – 1.2	0.8 - 1.4			Patolia *et al.* (2007)
4.91	0.9	1.75	0.31	0.68	Wani *et al.* (2006)

As organic manure, the seed cake can make a valuable contribution to micronutrient requirements. Table 7 presents an analysis of the micronutrient content by Patolia *et al.* (2007).

TABLE 7: **MICRONUTRIENT CONTENT OF JATROPHA SEED CAKE**

S%	Fe mg kg^{-1}	Mn mg kg^{-1}	Zn mg kg^{-1}	Cu mg kg^{-1}
0.2 – 0.35	800 – 1000	300 – 500	30 – 50	18 – 25

Source: Patolia *et al.* (2007).

Fuel

The seed cake has a high energy content of 25 MJ kg^{-1}. Experiments have shown that some 60 percent more biogas was produced from jatropha seed cake in anaerobic digesters than from cattle dung, and that it had a higher calorific value (Abreu, 2008). The residue from the biogas digester can be used further as a fertilizer. Where cow dung is used for household fuel, as in India, the seed cake can be combined with cow dung and cellulosic crop residues, such as seed husks, to make fuel briquettes.

USING THE FRUIT SHELLS AND SEED HUSKS

Biogas has been produced from fruit shells. In addition, trials showed that seed husks can be used as a feedstock for a gasification plant (Staubmann *et al*., cited Achten *et al*., 2008).

Jatropha fruit shells and seed husks can be used for direct combustion. Since the shells make up around 35–40 percent of the whole fruit by weight and have a calorific value approaching that of fuelwood, they could be a useful by-product of jatropha oil production. As shown in Table 8, the calorific values of *Prosopis juliflora* (a fuelwood species of semi-arid areas) and jatropha fruit shells are similar. However, four times the volume of fruit shells is required to equal the heating value of fuelwood, due to their lower bulk density.

Seed husks have a higher heating value and greater bulk density which makes them more valuable than the fruit shells as a combustible fuel. However, the technology required to separate the seed husk from the kernel is more suited to large processing plants than small rural industry.

TABLE 8: **THE VALUE OF JATROPHA FRUIT SHELL AND SEED HUSK FOR ENERGY PRODUCTION**

	WOOD (*PROSOPIS JULIFLORA*)	BIOMASS BRIQUETTES	JATROPHA FRUIT SHELL	JATROPHA SEED HUSK
Bulk density kg m^{-3}	407	545	106.18	223.09
Ash content % dm	1.07	8.77	14.88	3.97
Calorific value kcal kg^{-1}	4018	4130	3762	4044

Adapted from: Singh *et al.*, 2007, cited Abreu (2008).

The fruit shells can be dried and ground to a powder and formed into fuel briquettes. A trial found that 1 kg of briquettes took around 35 minutes for complete combustion, giving temperatures in the range of 525ºC–780ºC (Singh *et al.*, 2008).

The ash left after combustion of jatropha shell briquettes is high in potassium, which may be applied to crops or kitchen gardens. The fruit shells and seed husks also can be left around jatropha trees as mulch and for crop nutrition. For jatropha grown on degraded land, this has clear advantages because nutrient re-cycling – through returning the seed cake to the plantation – is unlikely to happen, due to the effort required and the higher utility to be gained from applying the seed cake to high-value crops.

Photo: FAIDUTTI

CHAPTER 5

Genetic improvement

The traditional uses of jatropha as a hedge plant and the harvesting of various parts of the tree for medicinal uses have not encouraged selection for high seed or oil yields over time. As a result, jatropha currently has the status of a wild plant with low and variable oil yields. However, it also has a high potential for improvement by breeding high-yielding varieties and hybrids. The possible scale of this improvement can be seen by comparing some domesticated crops with their wild ancestors.

PRESENT STATUS

Breeding to raise oil yields became a focussed area of research with the 2004/5 surge in interest in jatropha – an effort led mainly by the private sector. Given the time required for promising accessions to mature and be evaluated, it is clear that work to improve yields through breeding is at a very early stage and that present jatropha plantations comprise, at best, marginally improved wild plants. As jatropha is mainly open pollinated, any genetic improvement to date has resulted from the effect of superior plants having been grouped and grown together.

A comparison of yields of wild varieties over four years under semi-arid conditions (shown in Figure 7 in Chapter 3) found that only 5 percent (one individual out of 19) gave a good yield approaching 1 kg. A little more than 50 percent gave poor yields of 200 grams or less. The study also found that individual yields of unimproved plants can vary up to 18-fold, although high-yielding plants were seen to be consistent over time, suggesting genetic rather than environmental causes. There are large variations in the oil content of jatropha seed, ranging from 25 to 40 percent. This needs testing over time and in different locations to determine the relative influence of genetic and environmental factors.

THE IMPORTANCE OF YIELD

Maximizing oil yield per ha requires breeding for seed size, oil content and for parameters that affect the number of seeds produced. The economic importance of yield can be seen in the sensitivity analysis in Table 9. Yield and price have a far bigger impact on profit than direct costs and, since price is market dependant, the aim must be to improve yield.

TABLE 9: **JATROPHA GROSS MARGIN SENSITIVITY ANALYSIS**

ITEM	GROSS MARGIN USD/HA	VARIATION %
Expected yield, cost and price	208	0
Yield increase of 50%	436	110
Price increase of 50%	558	80
Cost decrease of 50%	384	32

Source: Parsons (2008).

PRODUCTION-ORIENTED BREEDING OBJECTIVES

The following would be appropriate objectives to maximize oil yield:

- improve dry matter distribution, with greater assignment to fruit than to vegetative parts,
- increase the ratio of pistillate (female) flowers per inflorescence to staminate (male) flowers, in order to improve the potential for fruit formation,
- increase synchronicity of flowering and seed maturity in order to lessen the labour intensity and enable mechanization of harvesting,
- increase seed weight and seed oil content, and
- increase the number of branches, flowers, seeds and fruits.

Other breeding goals would be:

- improve oil quality,
- develop non-toxic varieties to ensure human safety and to add value by enabling the seed cake to be used as fodder, and
- improve plant architecture, with more branching for maximizing yield and lower plant height for easier harvesting.

PRO-POOR BREEDING OBJECTIVES

While maximizing oil yield is a priority breeding objective, there will be other objectives for small jatropha growers, especially poor farmers. These will be for those traits that minimize risk, such as having acceptable yields under low rainfall, and resistance to pests and diseases.

The following would be appropriate pro-poor breeding objectives:

- improve drought resistance and productivity under water stress conditions,
- increase pest and disease resistance in order to avoid need for costly agrochemicals,
- improve plant architecture to have deeper rooting and a smaller canopy to allow for intercropping,
- enable easier shelling and seed crushing suited to simple extraction technologies,
- increase productivity under low-to-medium soil nutrient conditions, and
- maintain inedible leaves to ensure its utility as a livestock hedge.

PRODUCING IMPROVED VARIETIES OF *JATROPHA CURCAS*

The success of any programme of genetic improvement is enhanced by the existence of a large and diverse gene pool. Unfortunately, the genetic resource base of *Jatropha curcas* in India, Asia and Africa is small (Jongschaap, 2008). It was thought that accessions from jatropha's centre of origin in Meso and South America would offer larger genetic variation and, indeed, studies found more genetic variation in accessions from this region. However, a recent study by Popluechai *et al.* (2009) found that accessions from Mexico and Costa Rica had a 70 percent similarity to accessions from other parts of the world. This may limit the potential of intra-specific breeding programmes for *Jatropha curcas*. The same study also raised the prospect of increasing heterozygosity by breeding inter-specific hybrids, such as *Jatropha curcas* x *Jatropha integerrima*. The hybrid was backcrossed to *Jatropha curcas* and the resulting progeny exhibited stable inheritance of general desirable characters.

Jatropha displays a phenomenon, perhaps associated with epigenetic mechanisms, whereby there can be large phenotypic variation among genetically identical plants – characteristics such as seed size and oil content can vary considerably despite their similar or identical genetic composition. For example, Aker (1997), studying flowering of a single accession from Cape Verde on a field in Nicaragua, discovered that flowering time, number of flowers and male-female flower ratio all varied substantially depending on soil fertility, soil moisture, precipitation, evaporation and temperature.

True-breeding improved progeny are still some years from commercialization. Field evaluations of promising accessions and new varieties grown from seed take at least two years. Plant breeders working on jatropha are now using modern genetic marker techniques that speed up the screening process, but these selections still need to be grown to maturity for validation.

Use of tissue culture can speed up the multiplication of high-yielding varieties. Producing large numbers of genetically identical plants from one individual under closely controlled laboratory conditions is an established technique for many plant species. In addition to mass production of new plants from scarce parent material, a further advantage is that the new plants are disease free. Researchers have had a 100 percent survival rate in producing jatropha from tissue culture, but the technique has not yet reached commercial scale.

It is also possible to graft the stems of superior clones onto strong seedling rootstocks in order to grow clones of genetically improved plants on strong taproots. However, there is little, if any, experience of grafting jatropha. While this is feasible, it is laborious and time consuming. The hollow stem may result in a weak graft union prone to break in windy conditions. Still, this merits consideration in view of the need to improve existing plantations established with poor planting stocks.

BREEDING GOALS


Photo: HENNING

PLATE 20: A high-yielding, early fruiting tree (7 months old) in Cambodia.

In the short term, the goal for crop improvement should be to produce superior cloned material by scaling up tissue culture techniques or, at least, using micro-cuttings. But it should be stressed that, due to the genetic-environment interaction, superior performance may not transpose to other growing sites and management regimes. In the longer term, improved varieties need to be developed based on provenance trials, the selection of superior accessions and by breeding inter-specific hybrids for a range of production practices and agro-ecological and socio-economic conditions.

Information on the results of breeding work by the private sector is limited but it may be assumed, given the global interest and investment so far, that advances have been made and that this investment in crop improvement will be ongoing. The private sector will focus its efforts on optimizing yield to maximize return on investment. It will remain for the public sector institutions to develop jatropha varieties with the pro-poor breeding objectives described above.

Photo: FAIDUTTI

CHAPTER 6

Experience of Jatropha in sub-Saharan Africa and South Asia

This chapter reviews selective experience from West Africa, East Africa and India. Lessons learned from successes and failures can help define the types of interventions most likely to contribute to poverty reduction through adopting sustainable systems of jatropha production and utilization.

West Africa – Mali

Much of Mali is semi-arid with rainfall ranging from less than 200 mm in the north to 1 200 mm in the south. Rural Malians have grown *Jatropha curcas* for centuries as a hedge plant to protect crops from wandering livestock and to reduce wind and water erosion of the soil. A study found that 1 m of hedge produced about 1 kg of seeds which yielded 0.2 litres of oil. Each village had an average of 15 km of hedge with capability of yielding 12 tonnes of seed – potentially making 2 400 litres of oil available for local utilization (Henning, 2007). Traditionally, women collected jatropha fruits to extract oil which they used for medicine and soap making.

Jatropha system project

In 1987, GTZ launched a development project to improve the utilization of jatropha hedges within the framework of a renewable energy programme.

The project developed a "jatropha system" to support renewable energy at the village level together with components that covered erosion control and soil improvement, promotion of women and poverty reduction.

- Renewable energy: used jatropha oil in Lister-type diesel engines as both fuel and lubricant to drive grain mills and water pumps. Continuity of supply of diesel or a diesel substitute in the form of jatropha oil is important in areas with poor road access and therefore irregular supplies. Producing jatropha oil more cheaply than bought-in diesel would help to assure continuity of supplies to remote villages.
- Erosion control and soil improvement: used jatropha hedges to reduce wind erosion and planted the hedges across slopes where their roots formed earthen bunds that reduced erosion by decreasing rainwater run-off and increasing infiltration. The seed cake was found to be a useful fertilizer in a country where organic matter is rapidly depleted and imported inorganic fertilizers are costly.
- Promotion of women: installed engine-driven grain mills to reduce the tedium of women's work. Engine-driven expellers allowed women to improve their traditional soap production methods and increase their cash incomes.
- Poverty reduction: improved community potential for accruing financial benefits by using locally produced oil in place of diesel which reduced the mill running costs and reduced cash outflow from the villages. Financial benefits also accrued from substituting seed cake for bought fertilizers, reduced crop losses from wandering livestock and decreased erosion (Henning, 2007).

The project concluded that similar projects would have the greatest chance of success in areas with:

- high transport cost due to remoteness or poor roads,
- extensive wastelands unfit for food and cash crop production,
- available labour for harvesting and processing, and
- high costs of mineral diesel fuels and thus an advantage to substitute with a cheaper domestic alternative.

GTZ (2002), based on its experience in Mali and Zambia, noted that certain local conditions must be met for the jatropha system to be successful:

- planting: plants selected must be adapted to the site and available in sufficient numbers,
- soap production: caustic soda must be available,
- oil production: simple mechanical oil mills must be available, and
- powering: diesel engines must be capable of running on pure plant oil.

Early in the project, a problem arose when men claimed ownership of the jatropha trees. They had allowed women to harvest seeds for making soap for their own use, but when the women attempted to turn this into a cash-generating activity, the men wanted a share of the proceeds. This led to some loss of interest in the project (Henning, 2004b).

A study of the system's economic viability found a 49 percent internal rate of return on investment in cases that fully accounted for internal transport costs and which used the Sundhara oil expeller[3] powered by the Lister-type diesel engine. Using the hand-operated Bielenberg ram press gave negative returns. The study concluded that the production of jatropha oil was competitive with imported diesel (Henning, 2004b). However, local diesel prices change according to variables such as oil prices and exchange rates, so it cannot be assumed that jatropha oil will always remain competitive with diesel.

In fact, only one year later, Brew-Hammond and Crole-Rees (2004) found and reported that jatropha oil was not competitively priced and, as a result, the GTZ project was terminated. However, they also reported that the Mali Folkecentre, a Bamako-based NGO, felt the audit did not account for the added value of soap making and other products, that the price of jatropha seeds had since fallen, and that a cheaper supplier of the Sundhara oil press had been identified. The Mali Folkecentre continues to initiate projects in jatropha technology transfer and development of sustainable management models.

The GTZ project found soap production to be quite profitable. Three litres of oil could be extracted from 12 kg of jatropha seed, producing 4.7 kg of soap worth USD 4.20 and 9 kg of seed cake worth USD 0.27. Factoring in the cost of seeds, caustic soda and labour which totalled

[3] The Sundhara oil expeller was developed by FAKT, a non-profit consulting engineering firm, for use by rural communities in Nepal.

USD 3.04, it still resulted in a profit of USD 1.43 that could be made from five hours work (Henning, 2004b).

Multifunctional platform project

In the mid-1990s, the Government of Mali, with support from UNDP and UNIDO, introduced a multifunctional platform (MFP) project. The MFP has a simple diesel engine that can power a variety of tools such as a cereal mill, a seed husker, alternator and battery charger. The engine also can generate electricity for lighting, refrigeration and to pump water. By June 2001, 149 platforms were operational and the project planned to install

BOX 3. **Mali – Lessons learned**

- Projects using the jatropha system have the greatest potential for success where there are extensive wastelands unfit for food and cash crop production. There also must be available labour for harvesting and processing that does not conflict with other demands.
- The economic advantage of substituting jatropha oil for diesel improves in regions with high transport costs.
- Power-driven oil expellers appear to be more efficient than hand presses. However, in terms of viability, they are not more successful if they are not affordable and easily repaired by local artisans. In terms of soap production, the hand press is less expensive and more suitable for small-scale soap production, which makes it more pro-poor.
- The Lister-type diesel engine is less costly than more modern diesel engines that are designed to run on pure plant oil (such as the Hatz diesel engine). The technology is simple and can be repaired by local engineers with rudimentary facilities.
- Jatropha production benefits from value addition, e.g. soap making, and from the value of by-products such as seed cake.
- Selection of plants adapted to the site and available in sufficient numbers is essential when planting jatropha.
- Gender-differentiated access to resources may prevent uptake of jatropha oil processing and income-generating opportunities. Extension workers and community facilitators need to work with men and women together to find ways to overcome social constraints.

platforms in 450 villages serving about 10 percent of the rural population by the end of 2004. It was proposed that 15 percent of the MFPs should run on jatropha oil (Henning, 2004b), but a 2004 review in Mali found only one doing so. The review found that the MFP project had significantly reduced poverty in rural areas, particularly for women, and the model was expanded to other West African countries (Brew-Hammond and Crole-Rees, 2004). Lessons learned from Mali are summarized in Box 3.

East Africa – Tanzania

Tanzania has a tropical equatorial climate. Its annual rainfall ranges from less than 600 mm in the central region to more than 1 150 mm in the coastal and western regions.[4]

Jatropha seed production

In Northern Tanzania, Messemaker (2008) found that the jatropha seed price tripled between 2005 and 2008. By 2008, the price was highly variable, ranging from TZS 180[5] to TZS 300 and even TZS 500 in the most remote areas. The main demand in 2008 was for seed for planting and producing seedlings. An analysis of the economics of producing jatropha seedlings for sale indicated high returns with gross margins of 55 percent regardless of the seed cost.

However, for small-scale jatropha farmers producing seed, the gross margin showed a poor return (see Table 10). From the lowest to the highest seed price received, the gross margin was estimated between –130 percent and +23 percent, without accounting for any plantation establishment costs.

No farmers were observed applying fertilizers or other inputs, and weeding was minimal. Seed cake had limited use – for biogas generation and making fuel briquettes – and its value as a fertilizer was not well known.

Based on limited data, the yield was estimated at 1.65 tonnes per ha. The yield required to break even was 1.9 tonnes at the mid-range seed price of TZS 200 per kg and 3.8 tonnes at the lower price of TZS 100 per kg.

4 Information for this section is taken from in-country studies by Henning and Messemaker (2008).

5 For this report, exchange rate of TZS 1 150.00: USD 1.00.

Whether these yields could be achieved with minimal expenditure on fertilizers, irrigation and pesticides is doubtful. In all, this suggests that profitability is low and that jatropha farming in this situation is a risky enterprise.

TABLE 10: **GROSS MARGINS FROM SMALL-SCALE JATROPHA FARMING, OVER ONE YEAR (TZS/HA)**

	LOW SEED PRICE	MEDIUM SEED PRICE	HIGH SEED PRICE
Costs			
Irrigation	12 250	12 250	12 250
Weeding	24 500	24 500	24 500
Harvesting	343 000	343 000	343 000
Total costs	379 750	379 750	379 750
Revenue			
Harvest (kg/ha)	1 653	1 653	1 653
Price (kg)	100	200	300
Total revenue	165 300	330 600	495 900
Net benefit	-214 450	-49 150	116 150
Gross Margin	**-130%**	**-15%**	**23%**

Adapted from Messemaker (2008).

One large farmer confirmed low yields of about 1 tonne per ha, despite using seed sourced from various countries. Another said that seed sales could not cover the cost of harvesting. Gross margin calculations showed that large-scale farming was highly unprofitable if fertilizers, pesticides and irrigation were used, although this was based on very limited data (Messemaker, 2008).

Production of jatropha oil

The Vyaumu Trust, established by the Evangelical Lutheran Church of Tanzania, provided farmers with a locally manufactured Sayari oil expeller, originally developed for processing sunflower seeds. This was based on the diesel-powered Sundhara expeller (referred to earlier) that was used by GTZ in Mali.

Messemaker found that oil extraction was more profitable than growing jatropha. The figures are shown in Table 11.

TABLE 11: **GROSS MARGINS OF MANUAL OIL EXTRACTION OF 8 LITRES IN ONE DAY FROM 40 KG SEED (TZS)**

	LOW SEED PRICE[a]	MEDIUM SEED PRICE[b]	HIGH SEED PRICE[c]
Cost			
Seeds	4 000	8 000	12 000
Labour	2 500	2 500	2 500
Depreciation	153	153	153
Total cost	6 653	10 653	14 653
Revenue			
Extracted oil	16 000	16 000	16 000
Net benefit	9 347	5 347	1 347
Gross margin	**58%**	**33%**	**8%**

[a] TZS 100 per kg, [b] TZS 200 per kg, [c] TZS 300 per kg
Source: Messemaker (2008).

An extraction efficiency of 1 litre of oil from 5 kg of seed was used in the analysis, although the efficiency was observed on occasions to fall to 1 litre from 8 kg of seed. The jatropha oil price was always around TZS 2 000 per litre, whereas the seed price varied by area and supplier. The break-even seed price was TZS 334 per kg, above which oil production would be unprofitable. High seed prices in 2008 threatened the short-term viability of this business, but long-term oil extraction would appear profitable. Respondents confirmed the viability of mechanical oil extraction using powered Sayari expellers.

Soap production

Kakute Ltd, one of the Tanzanian organizations promoting jatropha for oil production, erosion control and soap making, conducted an evaluation in 2003 of the profitability of jatropha-related activities. It found soap making to be more profitable than oil extraction which, in turn, was more profitable than seed collection or production (see Table 12).

TABLE 12: **PROFITABILITY OF JATROPHA-RELATED ACTIVITIES**

ACTIVITY	RETURN ON LABOUR USD PER HOUR
Collection and sale of jatropha seeds	0.29
Oil extraction	1.09
Soap making	2.82

Source: Henning (2004b).

Soap produced from jatropha is sold as a medical soap, effective in treating skin ailments. Henning (2004b) noted that jatropha soap is sold in dispensaries at a higher price than other soaps on the market.

Photo: MESSEMAKER

PLATE 21: Jatropha soap, Tanzania.

However, Messemaker (2008) found soap production to be less profitable. The gross margins of the Kakute Ltd and Messemaker studies were not directly comparable, as the Messemaker study factored in fixed costs of rent and equipment depreciation, and higher costs for packaging materials. The Messemaker study respondents indicated that many people had stopped making soap due to the high price of jatropha oil.

Limited demand for the product, at three times the price of other soaps, was probably a contributing factor. On a small scale, with low overheads, soap making may be considered marginally profitable at an oil price of TZS 2 000 per litre.

Use of jatropha oil

Two northern Tanzanian firms, Diligent Energy Systems and InfEnergy, both with experience in producing biodiesel from jatropha oil, reached similar conclusions:

- manual seed selection is necessary,
- powered oil expellers are most economical,
- continual laboratory quality testing is required, and
- methanol must be imported as none is produced in-country.

By 2008, both firms had ceased production of biodiesel from jatropha oil, due to the high price of jatropha seeds. Economic viability could only be achieved at prices of TZS 30–40 per kg, indicating that producing biodiesel from jatropha was not profitable (Messemaker, 2008).

The Kakute stove, a cooking stove using jatropha oil developed by Kakute Ltd, proved unpopular due, in part, to the price of jatropha oil which, at USD 2.00 per litre, was three times the price of diesel and kerosene (Henning, 2004b). In addition, Messemaker (2008) found that jatropha oil was not used for cooking or lighting because the jatropha oil stoves and lamps did not work satisfactorily.

A number of organizations installed multifunctional platforms (MFPs)[6] in rural areas with plans to scale up the programme. For example, the towns of Engaruka and Leguruki both had MFPs in 2008.

[6] A multifunctional platform consists of an energy source (usually a diesel engine) mounted on a chassis, that powers a variety of end-use equipment such as grinding mills, de-huskers, oil presses, battery chargers and generates electricity for lighting, welding, refrigeration and water pumping.

However, in Engaruka, there were ownership and management issues with the MFP and it was not in operation. The Engaruka MFP charged TZS 3 000 (USD 2.61) per month for electricity with permission to connect two light bulbs. The maximum number of consumers possible for its generating capacity was 100, although there had only been 24 subscribers. The actual running costs per household when fully subscribed, excluding installation costs, was TZS 5 595 (USD 4.87) per month (see Table 13).

The Leguruki MFP had no oil expeller and so was running on mineral diesel. During daylight hours, it provided services such as grain milling, and at night, it generated electricity for six hours.

TABLE 13: **ENGARUKA MULTI-FUNCTIONAL PLATFORM COSTS PER MONTH (TZS)**

INVESTMENT COSTS (INSTALLATION)	TZS	USD[a]
MFP	135 000	117.39
Mini-grid	133 333	115.94
Pre-paid meter for 100 HHs	100 000	86.96
Connection for 100 HHs	66 667	57.97
Total installation cost	435 000	378.26
VARIABLE COSTS		
Maintenance (at 10% of installation)	43 500	37.83
Electricity 6 hours per day – diesel		
Diesel – 6 litres per day	366 000	318.26
Operation and management (2 workdays)	150 000	130.43
Total running cost excluding installation	559 500	486.52
COST PER HH USING DIESEL	**5 595**	**4.87**
Total cost with installation	994 500	864.78
Cost per HH	9 945	8.65
Electricity 6 hours per day – jatropha oil		
Jatropha seed required including for oil for expeller	903.9 kg	
Seed cost per TZS / Kg	300	0.26
Total seed cost	271 159	235.80
Operation and management (2 workdays)	152 093	132.25
Total electricity running cost on Jatropha oil excluding installation	466 752	405.87
COST PER HH USING JATROPHA OIL	**4 675**	**4.06**
Total cost with installation	901 752	784.13
Cost per HH	**9 017**	**7.84**

aExchange rate of TZS 1 150: USD 1.00. Source: Adapted from Messemaker (2008).

Comparing the cost of kerosene lamps and off-grid electricity strengthens the case for MFPs as a pro-poor technology. An average household using 6 to 9 litres of kerosene per month will spend approximately TZS 12 000, while the full cost per household for power from a jatropha-fuelled MFP is TZS 9 017 per month.

Using jatropha oil with a seed cost of TZS 300 per kg would reduce the subscriber cost to TZS 4 675 (USD 4.07) per month. The seed cost would need to rise above TZS 400 before diesel would be the cheaper option. The calculations assumed no consumer tax would be imposed on the oil. There was no metering of consumption and no use of low energy light bulbs which would make utilization more efficient. Box 4 summarizes the Tanzanian lessons learned.

BOX 4. **Tanzania – Lessons learned**

- Jatropha seed production is marginally profitable at best, based on present varieties and agronomic practices. Short-term profitability may be high where the price is inflated by demand for seed for planting. Lack of knowledge and low productivity are the main obstacles to profitable farming of jatropha.
- Jatropha oil extraction and soap making are both more profitable than growing jatropha. The scalability of soap making is limited by local market demand. Regional and overseas markets need to be explored.
- Biodiesel production was not feasible in 2008 when the jatropha oil price was TZS 2 000 per litre compared to the diesel retail price of TZS 1 600 per litre.
- MFP units are most in demand for de-husking and milling grains, according to the UNDP project. While provision of off-grid electricity using MFPs appears to be less costly than kerosene lamps, breakdowns, fuel shortages and operational issues probably constrain greater acceptability. It is important that the MFPs use sustainable technology in remote environments to avoid extended periods of non-operation.
- Using jatropha oil instead of diesel can lower running costs of MFPs when the costs of jatropha seed and oil extraction are included in the business model. This assumes no increased repair costs or depreciation resulting from using oil in the place of diesel.
- Jatropha oil-burning stoves and lamps need further improvement before widespread acceptance can be expected.

Asia – India

Between 1986 and 2003, farmers in Nashik, Maharashtra State, began growing *Jatropha curcas*, reaching a peak in excess of 8 000 ha involving more than 2 500 farmers. The planting material was sourced globally but yield expectations were not met and, after seven years, yields stabilized at less than 1.25 tonnes per ha. The optimum spacing was found to be not less than 3.0 x 3.0 metres and, while irrigation increased vegetative growth, there was a less-than-proportionate increase in yield. The plantations were abandoned by 2003, mainly because of low seed yield, poor oil content and poor or variable oil quality. The trees' non-uniformity was easily observed in the field (Ghokale, 2008).

In 2003, India set up a "national mission" to plant jatropha in wasteland areas. With a goal of using jatropha to meet renewable energy needs, in spite of the failed Nashik project, strong government support for jatropha has included setting guaranteed prices at the state level and making various grant schemes available. Research into the agronomy and utilization of jatropha in India has led to gaining meaningful field experience.

Community scheme wasteland development

In 2004/5, as part of the national mission, India's National Oilseeds and Vegetable Oils Development Board (NOVOD) launched a jatropha research and improvement programme, coordinating input from 35 institutions across 23 states. They collected 726 jatropha accessions, followed by yield trials and agronomic research.

Through a cooperative effort by NOVOD, ICRISAT and the District Water Management Authority (DWMA), projects were initiated in Ranga Reddy and Kurnool Districts of Andhra Pradesh for the rehabilitation of degraded lands to improve the livelihoods of the rural poor, through growing *Jatropha curcas* and *Pongamia pinnata* for oil production. The strategy involved the use of degraded common property resource (CPR) lands held by the *panchyat* (local village council). Self-help groups of landless people and small farmers were formed with the assistance of a local NGO, and thrift and credit activities were initiated. Labour for establishment and care of the plantation was paid for at the rate of Rs 60 per workday as an employment creation scheme.


Photo: BRITTAINE

PLATE 22: Jatropha plantation on wasteland, Velchel, Andhra Pradesh.

In Ranga Reddy District, this benefited 80 members of the local Velchel community. While the scheme members were given usufruct rights to the land for harvesting the produce, the land and trees remained in public ownership.

The Velchel plantation was established in 2005 with 150 ha of jatropha planted at 2.0 x 2.0 metre spacing with lines of pongamia every 100 metres. The annual rainfall in the area is 780 mm. The soil, a stony laterite, is deficient in nutrient and organic matter.

Plantation operations reportedly carried out included:

- watering in the first year only, to aid establishment of the tree seedlings,
- ring weeding the trees and laying the cut weeds as mulch,
- fertilizing the trees in 2005 and 2007 with 25 kg per ha each of diammonium phosphate (DAP) and urea, with plans to continue to apply every other year,
- digging basins around the trees and staggered trenches across the slopes, to trap water and encourage infiltration,
- pruning, to increase branching, and
- intercropping the trees in the first year with pigeon pea, millet and castor bean (although crops were subsequently destroyed by grazing animals).

No insecticides were used, although insect pests were present, in particular the scutella bug and termites.

The 2008 harvest yield – 40 grams per tree – was equivalent to 100 kg per ha (Wani, S. P., personal communication, 23 April 2009). The yield is projected to be 1 000 kg per ha by 2011 (Wani *et al.*, 2008). The trees on the plantation were seen to be highly variable with male/female flower ratios of 5:1 to 30:1. Velchel was expected to benefit from the installation of a jatropha oil-fuelled diesel power unit and power-driven oil expeller in the village. Farmer respondents thought it likely that seed cake would be used for fertilizer on higher value food crops.

A gross margin analysis for 2008 and a projection for 2011 are shown in Table 14. This does not include fixed costs of establishment, infrastructure, rent and scheme administration.

TABLE 14: **GROSS MARGIN FOR JATROPHA SEED PRODUCTION ON MARGINAL LAND AT VELCHEL**

	YEAR 2008 *(no fertilizer)*			**YEAR 2011 *(with fertilizer subsidy at 2008 prices)***		
	Units /ha	**Rs/ha**	**USD/ ha[d]**	**Units/ ha**	**Rs/ha**	**USD/ ha[d]**
DAP fertilizer (kg/ha)	0	0		50	1 350 [a]	32.40
Urea fertilizer (kg/ha)	0	0		50	850 [a]	20.40
Labour for fertilizing, weeding, pruning [b]	44 work days	2 640	63.36	44 work days	2 640	63.36
Labour for harvesting, husking [b]	25 work days	1 500	36.00	25 work days	1 500	36.00
Total variable costs		4 140	99.36		6 340	152.16
Seed production (kg)	100	1 000c		1 000	10 000[c]	
Net benefit (loss)		(3 140)	(75.36)		3 660	87.84
Gross margin		**-314%**			**37%**	
Yield (kg/ha) to achieve B/E	414			634		

[a] 2008 subsidized farm-gate price for DAP of Rs 27 000 per tonne and for urea of Rs 17 000 per tonne.,

[b] Rate paid of Rs 60 per workday., [c] Jatropha dry seed sale price of Rs 10 per kg., [d] USD 1.00 = R 41.67 (June 2008).

Source: Brittaine (2008).

The gross margin, with a 50 percent fertilizer subsidy, is projected to be positive at plantation maturity and for yields in excess of 634 kg per ha. DAP and urea will be applied in alternate years at the rate of 50 kg per ha each. No fertilizer was applied in 2008, which would go some way towards explaining the low yield. However, other important benefits will accrue from implementing this type of scheme and which should be accounted for, including employment generation in remote rural areas, reclamation of degraded land and the sustainable local production of a renewable energy source. Lessons from India are summarized in Box 5.

BOX 5. **India – Lessons learned**

- Despite using seed sourced worldwide, India's experience with growing jatropha has included variable phenotypes with low yields, and poor oil content and quality. Yet low seed yields can be part of a sustainable model, as shown by the NOVOD–ICRISAT–DWMA initiative. The initiative included broader objectives such as embracing wasteland reclamation, employment generation and local production of renewable bioenergy to improve living standards and catalyse the development of the rural non-farm sector. The question is whether continued government support is sustainable and whether the approach is scalable.
- Land tenure problems can arise with wasteland reclamation programmes due to uncertain ownership and the potential for future competing land claims as the land becomes productive. Retaining public ownership but allowing usufruct rights appears to be a workable solution.
- The inclusion of other tree oilseed species in jatropha plantations is a pro-poor strategy, such as Velchel's inter-planting of jatropha with slow-maturing *Pongamia pinnata* and the fast-maturing castor bean. Intercrops may be damaged by grazing livestock, meaning planting boundaries of jatropha may be worthwhile.

Photo: FAIDUTTI

CHAPTER 7

Jatropha for pro-poor development

While the aim of pro-poor development is to increase economic benefits to the poorer members of society, such development should not unduly threaten food or water security, reduce access to land or create poor working conditions. Pro-poor development should be specifically pro-women in order to address the gender imbalance of access to economic opportunities, health and education in developing countries. Pro-poor development has to be sustainable, including the need for environmental sustainability.

This chapter examines the importance of biofuels and the potential of jatropha for poverty reduction, together with the risks jatropha biofuel development presents to the livelihoods of the rural poor and to the environment. It further characterizes jatropha production systems and concludes with the conditions required for jatropha to make a meaningful impact on pro-poor development.

BIOFUELS – AN OPPORTUNITY FOR THE RURAL POOR

Almost 2.5 billion people in developing countries earn their livelihoods from agriculture. Of these, 900 million live below the poverty line of USD 1.00 a day. In addition, agriculture directly employs 1.3 billion people, or 40 percent of the global labour force, yet agriculture only contributes around 4 percent of global GDP (some USD 1.6 trillion).

The first issue is whether, if these people stay in agriculture, the agricultural basket of commodities and products is large enough to improve their incomes and lift them out of poverty. As this is unlikely, the only possibility is to reverse the long-term decline in food prices and expand the basket (Figure 10 shows the general decline in food prices of major commodities from 1900 to 2008). Of the several price peaks in the past century, the 2007–2008 food price peak was the most extreme. It was due largely to higher oil prices and the parallel increased demand for biofuel feedstocks being addressed through the use of food crops such as maize.

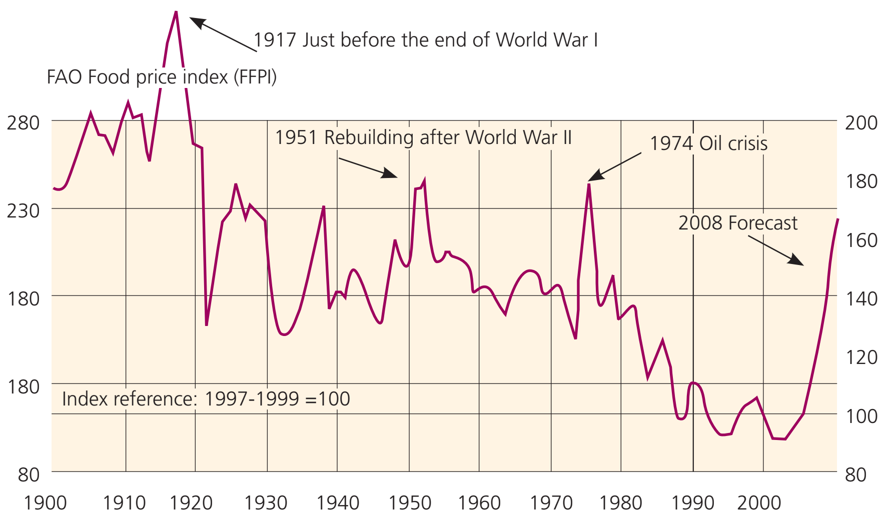


FIGURE 10: **Food prices 1900 – 2008.**

Source: UNEP/GRID-Arendal (2009): Hugo Ahlenius, Nordpil.

The second issue is whether these people could move out of agriculture. If half the agricultural labour force moves out of agriculture in the next 20 years, it is unlikely that these 650 million people can be absorbed into other sectors in developing countries. This is a large number compared to the GDPs of the OECD countries and the numbers of people employed. In 2008, the USA had a USD 14 trillion economy with a labour force of 153 million and an unemployment rate of 5 percent. At the same time, the EU had a USD 16 trillion economy with a labour force of 222 million and an unemployment rate of 9 percent. However, in the USA and EU, 15 to 20 percent of the labour force is employed in activities related to agroindustry and agricultural services.

The agricultural basket is small and, unless it is expanded through new commodities and related agro-industries and agricultural services, the prospects for reducing poverty through development of the agriculture and associated sectors remain bleak. However, prospects improve when the agricultural basket is expanded to include biofuels, because the energy market is so much larger. This underscores the importance of biofuels in alleviating poverty. However, any effort to do so must be undertaken responsibly, addressing both food security and environmental concerns.

CHARACTERIZATION OF JATROPHA PRODUCTION SYSTEMS

Jatropha production systems are beginning to emerge that can be differentiated by scale, ownership and objective. Some differentiation is attempted here, by describing the main characteristics and their relative contribution to potential poverty reduction. These production systems are (see Figure 11 on page 81):

- plantation
- plantation on wasteland areas
- outgrower schemes
- plantation + outgrower schemes
- smallholder production
- livestock barrier hedges

Plantation: These schemes are in excess of 5 ha, under either public or private ownership. In 2008, plantations represented around 20 percent of the area planted to jatropha, with governments being the main drivers. This sector is expected to see the greatest growth in the next five years. By 2013, it is anticipated that nearly 50 percent of jatropha planting will be large scale, of which more than 20 percent will be plantations in excess of 1 000 ha.

Growth of plantation schemes will be driven by investments from the major oil companies and international energy conglomerates (Gexsi, 2008) with the objective of jatropha oil production. There is little expectation of further investment for the local production of biodiesel.

Plantation schemes have the least potential to enhance rural development but they increase rural employment opportunities, and their development investment and risk are borne by private financial and state institutions rather than by farmers.

Plantation + outgrower schemes: This model places the investment risk of growing jatropha onto the farmer. The upside is support in the form of improved planting material, inputs and agronomic advice. The potential of this type of scheme for pro-poor development will depend on the level of support from the central organization and the terms of contract. Smallholder outgrowers play a significant part in growing jatropha, more so in Africa and Asia than Latin America. There have been reports of failures of outgrower schemes, which may shift the concentration of future growth to plantations (Gexsi, 2008).

Outgrower schemes: As above but there is no association with a commercial plantation. Outgrowers are smallholder producers who are contractually linked to a central organization for seed purchase and oil extraction.

Smallholder production: With smallholder production, small farmers do not have contractual purchase agreements but, instead, sell seed to local middlemen. NGOs support small farmers' groups by providing technology and advice for the local production and use of jatropha oil, allowing more added value to be retained in the local community. This leaves small farmers able to pursue their own objectives, such as more sustainable production systems with less risk through permanent intercropping with food and other crops.

Livestock barrier hedges: This system of jatropha production and utilization is most evident in dry regions, especially in Mali. Jatropha hedges provide soil erosion control, increase water entrapment and infiltration, and protect crops from wandering livestock as well as oil production for local use.

The extent to which these production models can contribute to pro-poor development is summarized in Figure 11.

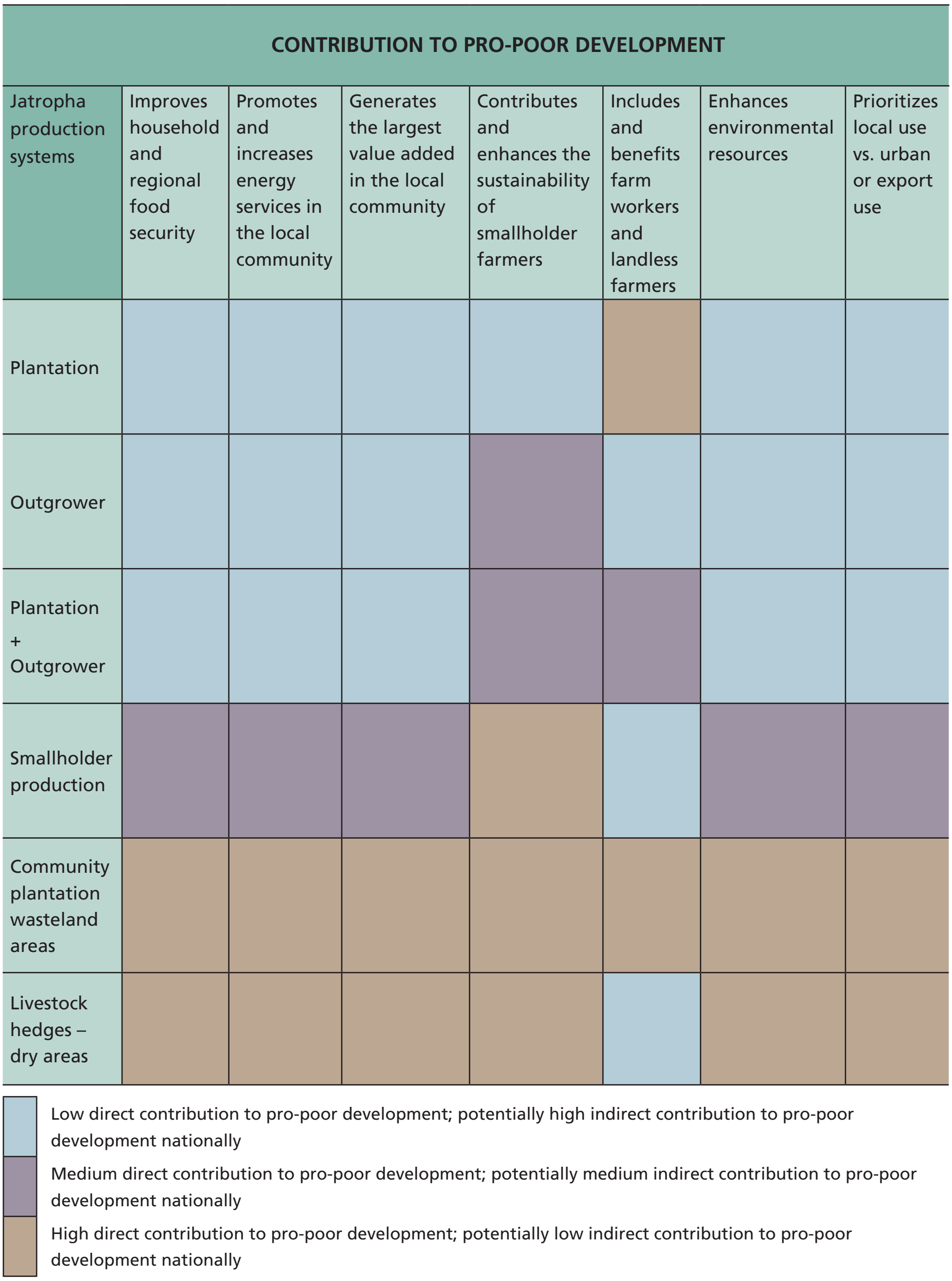


FIGURE 11: The relative extent to which jatropha production systems are likely to directly contribute to pro-poor development.

JATROPHA – AN OPPORTUNITY FOR THE RURAL POOR IN SEMI-ARID REGIONS

The opportunities for agricultural activities are limited in the dry areas of the world where intensive agriculture is difficult and there is increasing environmental degradation. Biofuel production can be especially beneficial to poor producers, particularly in remote areas far from consumption centres, where inputs are more expensive and prices lower, thus making food production, by and large, non-competitive. In areas that are both dry and remote, there is little opportunity for alternative farming strategies. Niche products can be developed, but relatively few people will benefit due to limited demand. Jatropha offers a potential opportunity in such regions to strengthen rural livelihoods.

OPPORTUNITIES FOR POVERTY REDUCTION

Poverty springs from a lack of income and assets, and particularly a lack of empowerment that limits livelihood options. The cultivation of jatropha for seed production expands livelihood options with the opportunity to earn income for smallholder growers, oil mill outgrowers and members of community plantation schemes or through employment on private-enterprise jatropha plantations.

Women especially can benefit, because milling machines powered by diesel engines fuelled with jatropha oil reduce the amount of tedious work they must do. Using jatropha oil as a replacement for traditional biomass cooking fuels is also healthier, as cooking is done in a smoke-free environment, and women do not have to spend time gathering fuelwood. The decreased need for fuelwood also relieves pressure on forest resources.

Small businesses in the rural non-farm sector can become more efficient with availability of a cheaper and more dependable fuel source, for example to power cutting and grinding machinery. Using jatropha oil to fuel irrigation pumps and two-wheeled tractors can increase agricultural efficiency.

Addressing energy poverty by growing jatropha and using its oil within rural communities for diesel-powered electricity generation offers benefits for health, education and information, because:

- healthcare improves with provision of power for refrigeration of vaccines,
- education benefits from better light for extending studying hours,
- information access improves when electricity can power cell phones, computers, televisions and radios, and
- health and education professionals are more likely to live and work in remote rural areas if living conditions are made more comfortable through the provision of electricity.

There is an opportunity to increase the value of the natural resource asset base of the rural poor by utilizing jatropha's ability to grow on poor and saline soils in dry regions.

The use of seed cake as fertilizer and jatropha's potential to reduce erosion can halt or reverse land degradation. The use of seed cake for livestock feed is a potential opportunity to improve the efficiency of rearing livestock, if non-toxic varieties are developed. However, if seed cake is used for feed or energy production instead of fertilizer, the capacity of jatropha growing for land reclamation will be lessened. An assessment will be needed of the values of alternative products that minimize the opportunity cost.

As elaborated earlier, there are larger scale jatropha production systems that also offer pro-poor development opportunities through, for example, wage employment, contract farming leading to increased productivity and incomes, and reduction in local consumer price of biodiesel.

Further opportunity for poverty reduction in the form of carbon payments for liquid biofuel production – which will be possible through Clean Development Mechanism (CDM) procedures – are designed to enable applications by small producer groups. The CDM enables industrialized countries to finance low carbon emission technologies in developing countries as an alternative to more costly technologies for reducing GHG emissions in their own countries. Box 6 (see page 84) highlights appropriate strategies for pro-poor development of jatropha.

Apart from the opportunities, there are risks to the sustainability of jatropha bioenergy production in terms of economic viability. There are also risks to the environment and to society.

BOX 6. **Pro-poor strategies for jatropha development**

- Contribute to household and regional food security.
- Increase energy services in the local community.
- Generate the largest value added possible.
- Enhance the sustainability of smallholder farmers.
- Include farm workers and landless farmers.
- Enhance environmental resources.
- Prioritize local use *vs.* urban or export use.

ECONOMIC RISKS

Feedstock production, particularly the harvesting costs of jatropha, may prove excessive. Jatropha growing could prove uneconomical if higher oil-yielding and non-toxic varieties are not forthcoming. The level of economic returns that would attract and retain investment by the private sector may not be attainable on degraded lands. Figure 12, which compares the returns to labour for jatropha to other biofuel feedstocks, shows that jatropha compares poorly to sugarcane and oil palm, but much depends on the level of yield. There is an urgent need to improve jatropha yields through breeding and by addressing the knowledge gaps in jatropha feedstock production.

Low mineral oil prices will depress the biofuel market without price support. With a trend of long-term increases in the price of fossil oil prices, there will be fluctuations in the ability of biofuel feedstocks to compete with mineral oil. However, long-term price supports may not be a sustainable option for many countries.

Bioenergy from jatropha could become obsolete as second and third generation technologies reach commercial scale. Measures should be considered to ensure that value chains have the means and resources to adapt to emerging opportunities as these new technologies come on-stream.

Potential earnings from carbon emission reductions (CERs) may be jeopardized by intensive production systems that seek to maximize yields but which also may reduce savings in GHG emissions.

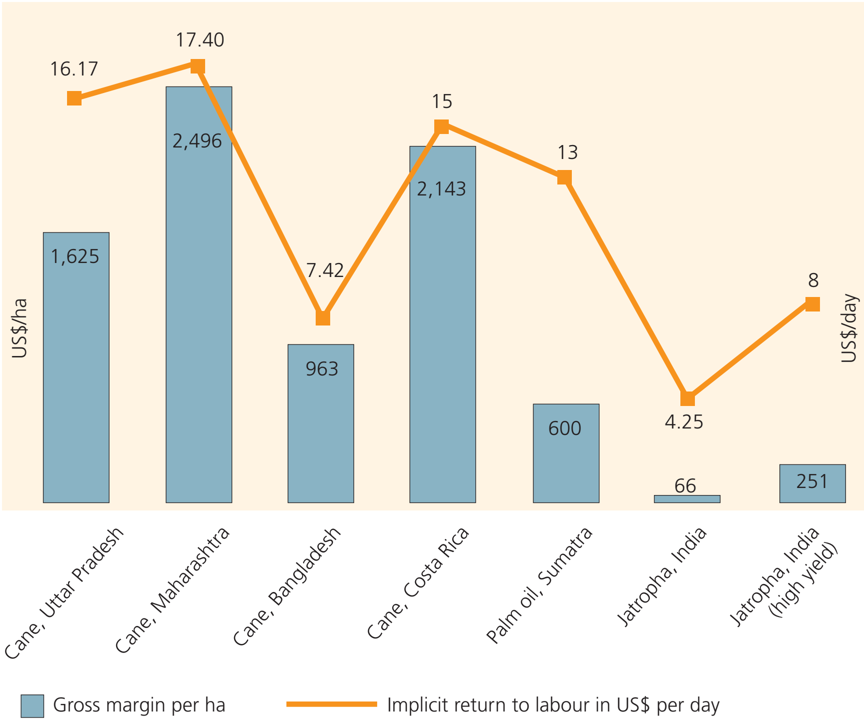


FIGURE 12: **Gross margins, returns to labour in biofuel feedstock production.**

Source: Gallagher (2008).

ENVIRONMENTAL RISKS

Negative impacts on biodiversity are to be expected where jatropha cultivation replaces natural ecosystems. To some extent, this may be mitigated by mixed species cropping with other biofuel crops, food or fodder crops, or timber species. Where jatropha is planted on degraded land, the risk to biodiversity is likely to be small.

Detailed life-cycle analyses of GHG emissions from jatropha biofuels are not available, but there is strong evidence that net GHG emissions will be lower if there are less intensive production systems, if feedstock production is on lands marginal for agriculture and if use of nitrogen fertilizer is avoided or kept to a minimum. In addition, the use of by-products for energy will increase the GHG savings. On the other hand, there will be less GHG emission savings if the oil is processed to biodiesel and if it is shipped to overseas markets.

Research is required to establish good farming practices for jatropha production by small producers as well as by large producers. Conservation agriculture practices under both extensive and intensive systems can help to optimize input use and offer higher productivities and returns with minimal environmental risks. It is likely that large-scale commercial production may have to be located in subhumid ecologies on soils with good production potential.

The effect on the environment of applying large quantities of seed cake fertilizer is unknown and research is required to ascertain whether this presents a risk. Mexican varieties are considered non-toxic, but they still contain curcin and residual levels of phorbol esters. There is also the risk of jatropha becoming a nuisance weed and threatening more fragile ecosystems by competing with and predominating native species.

RISKS TO SOCIETY

The economies of scale favoured by biofuels encourage the acquisition of large areas of land by private concerns. This threatens access to land by the poor in rural areas where land tenure systems are weak. Improved land administration systems that harmonize formal and customary land tenure will be required.

While large-scale production will create jobs in rural areas, these will be mainly low-skilled and seasonal. The labourers face the possibility of poor employment conditions and unsafe working practices for which government and pro-poor civil society institutions will need to establish checks.

Outgrowers under contract to supply large processors may face unfair business practice with lack of legal redress in the event of reneged contracts. Small farmers will have little negotiating power for settling sales terms and conditions with large private concerns unless they form effective cooperatives and producer organizations.

Jatropha cultivation is unlikely to reduce access to water supplies, as jatropha uses little water compared to other biofuel crops. However, large-scale biodiesel production will create a local water demand that may create conflict with other water users. Accidental pollution of potable water may also be a concern, given the large quantities of methanol required in the biodiesel production process.

Pre-existing gender inequalities may be sustained by biofuel development policies. Policies will be needed that promote gender equality and women's empowerment.

Using land to grow jatropha in place of food crops may threaten local food security if there is an absolute shortage of land. This risk will be reduced by using land unsuited to food crops for jatropha cultivation. However, there will be a tendency for private concerns to utilize better land to increase the return to capital invested and to situate plantations in areas with better transport links, neither of which are pro-poor in a production sense. Yet, they can contribute to poverty alleviation and rural development through on-farm and off-farm employment generation and by lowering the price of biodiesel, thereby making it more accessible to both rural and urban poor.

The toxicity of the seeds, oil and seed cake is a potential risk to human health, although clearly manageable if given proper attention.

The outlook is for more large-scale plantations to grow jatropha with increasing ownership by the private sector, which may contribute little directly to pro-poor development – but may do so indirectly through employment generation and reduction in the price of biodiesel. Therefore policies are needed that take into account the risks and benefits that can result from jatropha production and can guide jatropha development towards more equitable mix of production models.

POLICY CONCLUSIONS

At the global level, there is a need for coordination of biofuel development and an international food reserve system to protect the vulnerable poor. To meet pro-poor objectives, international support for research into jatropha agronomy and genetic improvement is needed. The development of non-toxic varieties should be a priority. CDM methodologies and certification to support sustainable jatropha production systems need to be accessible by the rural poor.

Taking advantage of the opportunity jatropha presents for rural development will require developing countries to address the policy, regulatory and public investment constraints that generally affect their agricultural development. Biofuels need to be integrated within a broader framework of investment in rural infrastructure and human capital.

Large-scale plantation type schemes should be promoted as part of the pro-poor development strategy to generate employment and incomes, and make biodiesel affordable to the poor.

Too much regulation of the biodiesel industry in the early stages could exclude small producers. Small feedstock producers can be assisted by legislation that sets quotas, requiring the large oil processors to source minimum quantities from small farmers.

The expectation that jatropha can substitute significantly for oil imports will remain unrealistic unless there is an improvement in the genetic potential of oil yields and in the production practices that can harness the improved potential. For the present, the main pro-poor potential of jatropha is within a strategy for the reclamation of degraded farmland along with local processing and utilization of oil in a way that can improve and diversify rural livelihoods, particularly for the disadvantaged rural poor in semi-arid regions. In addition, by providing physical barriers, jatropha can control grazing and demarcate property boundaries while at the same time improving water retention and soil conditions. These attributes, added to the benefits of using a renewable fuel source, can contribute in an even larger way to protecting the environment.

BOX 7. **Pro-poor jatropha policies and practices**

- Ensure strong commitment to pro-poor development. Pro-poor models will only succeed if guided in that direction.
- Target areas that are remote, have poor transport links or high costs for imported fuel.
- Target areas that are marginal for agriculture but also those marginal areas that can enhance food security and incomes.
- Integrate development of locally owned off-grid power and multi-functional platforms with jatropha production and processing in remote areas.
- Integrate the reclamation of degraded agricultural land with jatropha production, using the seed cake as fertilizer and employing conservation agriculture practices.
- Support large-scale jatropha production schemes that do not compete for land with food crops, in order to promote food production while increasing rural employment and access to biodiesel.
- Support research for better jatropha varieties and improved agronomic practices, including conservation agriculture and integrated pest and nutrient management.
- Support research and development of new uses of jatropha oil and its by-products.
- Promote responsible public-private partnerships to drive product development and address issues along the value chain.
- Legislate for large oil mill companies to purchase minimum quantities from small producers where large plantations predominate.
- Safeguard land and property rights, including communal property, of the rural poor.
- Be specifically pro-women, to address the gender imbalance of access to economic opportunities, health and education.

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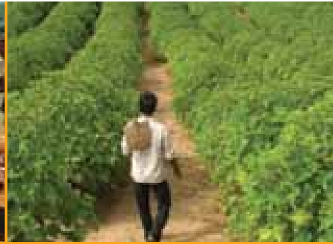


Jatropha: A Smallholder Bioenergy Crop
The Potential for Pro-Poor Development

This publication presents a compilation of information on key practical issues affecting jatropha for pro-poor development. The information, presented by specialists from around the world at the International Consultation on Pro-Poor Jatropha Development held in Rome, Italy in April 2008, is based on the knowledge available from research reports and ongoing unpublished research material.

This document provides a brief overview of biofuels, their growth drivers and their potential impacts on poor societies. It also summarizes the most recent data on the cultivation, seed harvesting, processing, uses and genetic improvement of jatropha, and gives an overview of experiences with jatropha production from case studies in sub-Saharan Africa and South Asia.

The information is provided to increase knowledge of jatropha throughout subtropical and tropical areas. It will also contribute to strengthening policies and strategies that recognize the potential of jatropha with regard to pro-poor development, sustainable rural income and improved livelihoods in developing countries.

This publication will interest a wide range of readers including government and institutional policy- and decision-makers, international and multilateral development organizations, donors, NGOs, the private sector and foundations as well as researchers, advisors, teachers and professionals in agriculture.

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