FACT FOUNDATION

Jatropha Handbook

First Draft

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Introduction

Jatropha Curcas has the advantage that not only is it capable of growing on marginal land, but it can also help to reclaim problematic lands and restore eroded areas. As it is not a food or forage crop, it plays an important role in deterring cattle, and thereby protects other valuable food or cash crops. Jatropha seeds can be pressed into bio-oil that can be used to run diesel engines, which in turn can drive pumps, food processing machinery, or electricity generators. The bio-oil can also be the basis for soap making. The pressed residue of the seeds is a good fertilizer and can also be used for biogas production.

Currently, it is difficult to assess the validity of the recommendations given. In Chapter 2, for example, the Indian source does not recommend vegetative propagation, although this generally seems to be an effective method.

Chapter 1: General data on Jatropha

(J de Jongh, 15-03-2006, edited by W. Rijssenbeek)

The term “Jatropha” is usually used to refer to the species Jatropha Curcas, although there are approximately 170 known species of the plant. Jatropha is at present still a wild plant – it is not cultivated through variety research. It belongs to the Euphorbia family.

The plant and its seeds are non edible (toxic) to animals and humans and are therefore used worldwide as hedges (living fences) to protect agricultural fields.

1.1 Physical description

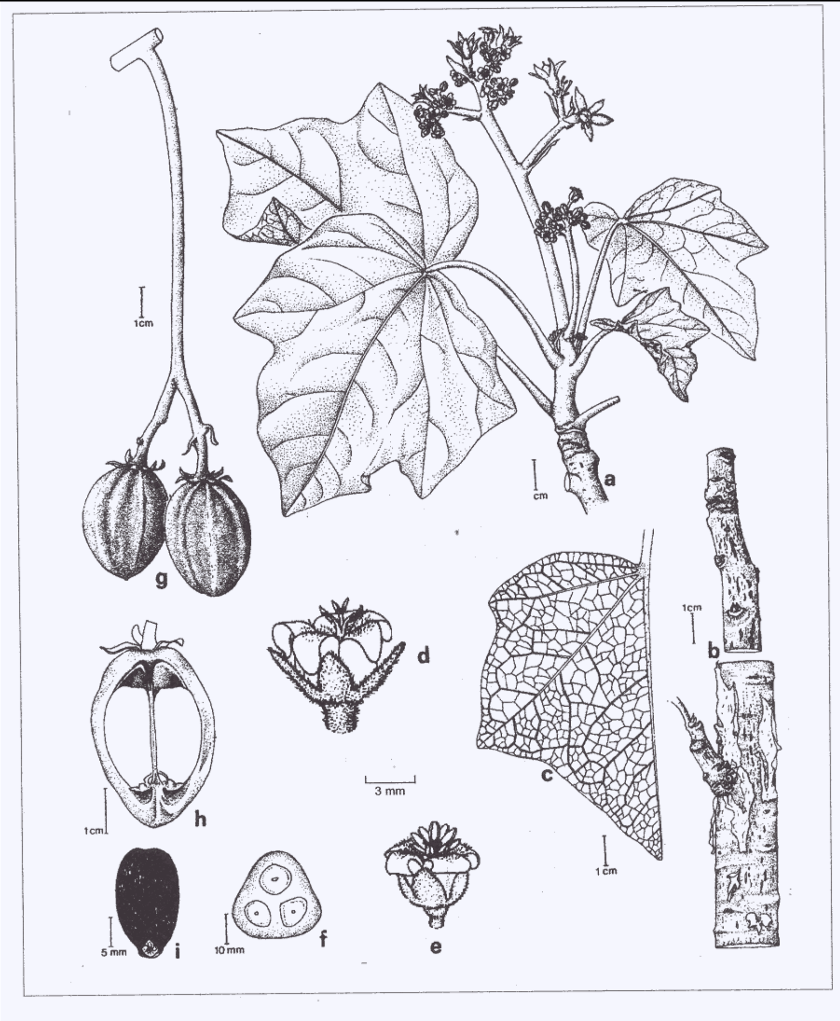

Fig. 2. Important parts of the physic nut: a - flowering branch, b - bark, c - leaf veinature, d - pistillate flower, e - staminate flower, f - cross-cut of immature fruit, g - fruits, h - longitudinal cut of fruits; a - c and f - h from Aponte 1978; d and e from Dehgan 1984 (reprinted with permission).

Fig 1: Nomenclature from [1]

It is a tall bush or small tree (up to 6 m height).

The lifespan of this perennial bush is more than 50 years, and it can grow on marginal soils with low nutrient content.

Jatropha Curcas, or "physic nut" has a straight trunk with thick branchlets.

It has green leaves with a length and width of 6 to 15 cm.

The fruits have an "American Football" type of shape, of about 40 mm length and each contains 3 seeds (on average), which look like black beans. with similar dimensions, of about 18 mm long (11-30) and 10 mm wide (7 – 11)

The seed weight per 1000 seeds is about 750 grams, which is equivalent of 1333 seeds per kg on average.

The seeds contain more than 30% of oil by weight. (Tz 38%, of which some 30% can be gained using cold pressing.)

The branches contain a whitish latex, which causes brown stains that are difficult to remove.

Normally five roots are formed from seeds: one tap root and 4 lateral roots. Plants from cuttings do not develop the tap root, only the laterals.

The appearance of the plants in a hedge can vary a lot. You may find plants with no leaves (dormant position) beside plants with green leaves. Both the availability of water and sunlight have influence on this effect.

1.2 Occurrence:

Jatropha originates from Mexico and Central America, but has spread all over the world and is mostly used for hedges.

Names used can also vary per region or country. It is most commonly known as "physic nut" or "hedge castor oil plant" (while castor oil comes from the castor plant , or mamona plant, which is a related species).

In Mali it is known as "pourghère"

In the Ivory Coast it is known as "bagani"
in Senegal it is known as "tabanani"

in Tanzania it is known as "makaen" / "mmbono"

1.3 Ecology

Jatropha is not a weed, and thus not self propagating. It has to be planted.
It grows well on marginal land with more than 600 mm rainfall per year, and it can withstand long drought periods.
It cannot withstand frost. Henning (see 2) says it can withstand slight night frost.

F 1: The various stages of fruit development can be seen, and an open fruit shows the (black) seeds inside.

F -2: Hosur India May 2004. The Jatropha have been planted (from grown seeds in bags) in 16-9-03 and were thus only 8 months old, and over 2 m tall, when taking this picture!


F-3: Plantation of Jatropha


F-4 Intercropping of Jatropha with maize.

1.4 Properties

Many investigations have been done on the content of the Jatropha seeds.
The seeds contain:

Material	**Kernel (60% of weight)**	**Shell (40% Of weight)**	**Meal**
Crude protein	25.6	4.5	61.2
Lipid (crude fat)	56.8	1.4	1.2
Ash	3.6	6.1	10.4
Neutral detergent fibre	3.5	85.8	8.1
Acid detergent fibre	3.0	75.6	6.8
Acid detergent lignin	0.1	47.5	0.3
Gross energy (MJ/kg)	30.5	19.5	18.0

Sources: [3,5]

The seed oil is 80 percent unsaturated, made up mainly of oleic and linoleic acid. Most vegetable oils that are liquid at room temperature have a comparable fatty acid composition.

Toxicology

The toxicity of the seeds is mainly due to the presence of “curcin” and “diterpine”.

”curcin” is similar to “ricin”, the same toxic protein as present in castorbean (Ricinus communis). “diterpine esters” (we call them phorbol esters) which have been isolated from seeds and roots.

Since the seed cake still contains oil, it also contains the toxic diterpenes, and so can not be used for fodder.

Until now, no mutagenic properties have been proved for the oil, and thus there is no (known) danger for workers.

1.5 Uses

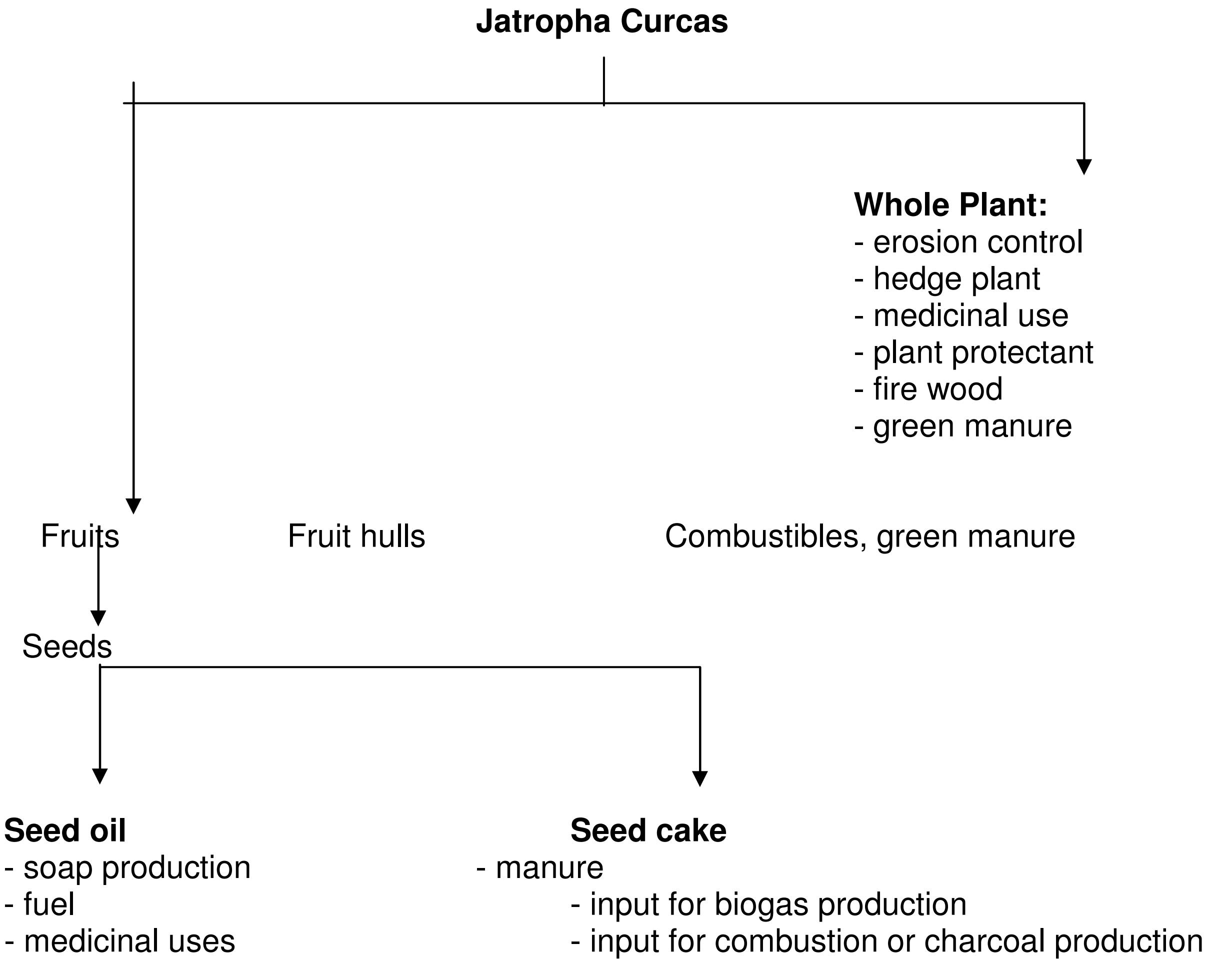

Fig 2: Overview of various uses

1.5.1 Use of the whole Plant:

Erosion control as hedge plant
In the tropics, the plant is widely used as a hedge in fields and settlements. It protects plants against wind erosion and keeps animals out. Jatropha is chosen for this purpose mainly because it can easily be propagated by cuttings, densely planted for this purpose, and because the species is not browsed by cattle. The roots also form a protection against water erosion, and can protect against soil erosion by runoff if planted with Vetiver grass or lemon grass.

When grown from seeds, the plants are edible for the first 3 months, since the toxic material has not been developed yet. It should be protected from animals in these early stages. It can also be eaten safely, when steamed or stewed.

Jatropha hedges are commonly used in Cape Verde, also for fighting soil erosion, Mali, Upper Guinea, Burkina Faso, Zimbabwe, and also in El Salvador.

F5: Dense jatropha hedges in Tanzania (Photo Ruud van Eck, Diligent)

Consumption of seeds or seed cake should be avoided in all cases!!

Medicinal use
The name "Jatropha" refers to medicinal uses, from the Greek iatrós, meaning "doctor" and "trophè", meaning "food".

Preparations of all parts of the plant, including seeds, leaves and bark, fresh or as a decoction, are used in traditional medicine and veterinary purposes. The oil has a strong purgative action and is widely used to treat skin diseases and to soothe pain from rheumatism.
The sap flowing from the stem is used to control the bleeding of wounds.

Plant protectant

Extracts from all parts of the physic nut showed insecticidal properties on plants (Grainge and Ahmed 1988).
Most of the experiments done are still in experimental stage.

Viruses
Unfortunately the physic nut is a host for viruses that attack also cassava, since they belong to the same family of plants (such as the cassava superelongation disease). Therefore physic nut should not be used to fence in cassava fields.

For some countries it should be investigated if it does not contain viruses for major crops. One issue raised in Mozambique, for example, was that it could possibly contain viruses harmful to cashew nut trees, which occur in large quantities all over the country.

Firewood and green manure
The plants and fruit hulls could be used for firewood, but it is low quality wood.
The leaves and the fruit hulls can be used as green manure in the fields.

1.5.2 Seed oil uses

The seed oil can be used for production of soap, directly as fuel in oil lamps or stoves, or as PPO for diesel engines.

Soap production.
In former times Portugal imported Jatropha seeds from the Cape Verde islands to produce soap. From the ‘20s to the ‘60s some 2000 tons of seeds were imported per year on average.

Presently soap is produced by artisanal methods in Mali and Tanzania (Arusha) and for short in Zimbabwe. The oil is boiled with a soda solution (Henning, 1994) and poured into moulds, in which it hardens out into soap during cooling of.
The soap has positive effects on the skin and is therefore marketed for medicinal purposes.The local production of soap is one of the most economically attractive uses of Jatropha oil.

In [2, The Jatropha system, Henning, 2004], some economic calculations are given for the production of soap, as well as the production of PPO, in Tanzania,.

F6: Left: Pongamia seeds, middle Jatropha seeds from Tanzania, right top: soap from Kakute Tanz, below, Oil from Diligent

Fuel

After pressing the seeds, the filtered oil can be directly used as PPO in diesel engines. Because of slightly different properties of PPO compared with fossil diesel, newer types of diesel engines must be adapted.
Generally the Diesel engine is very suited to run on PPO. In fact Rudolf Diesel designed his first engine to run on plant oil as well.
Many types of diesel engines have indirect injection (IDI) with pre-chambers. The PPO can be used freely in these engines, which are still commonplace in developing countries.
Some typical brand names are: Lister, Deutz, IFA, DMS, and Farymann. Probably most of these are IDI types. Elsbett diesel engines have been designed especially for the use of PPO. For more details, see section 5. Direct Injection diesels can also run on PPO, but some modifications have to be made to the engines. Mainly cold start and low-load situations (idling etc.) are dangerous when using PPO. A two-tank system, using PPO only for full load of the hot engine, overcomes most problems. The engine should be monitored properly for lubrication oil production or consumption and coke deposit in the combustion chamber.

To produce a generally usable biofuel for any diesel engine, the PPO can be converted to biodiesel with a trans-esterification process. The resulting biodiesel can be used in any diesel engine without adaptations (except for pure rubber hoses which detoriate after longer contact with pure biodiesel).

This is not a complex process, but requires the addition of methanol (or ethanol) and caustic soda, increasing the cost of the final product.
This is mostly done in Europe, notably in Germany and France, from rape seed oil.

This process, requires the use of electricity, and therefore bio-diesel production is typically feasible on a large scale, at centralised production plants.
It is not so suitable for small scale applications, although small systems have been designed in India, powered by human pedalling force (cycling). [6]

For more details, see section 5.

Medicinal uses
The oil can also be used for medicinal purposes, see earlier.

1.5.3 Seed cake uses

Manure
A good application for the seed cake is to use it as organic manure, replacing chemical fertilizer. It has a nitrogen content similar to that from cake of castor bean or chicken manure. The nitrogen content ranges from 3.2 to 3.8 %. (Juillet et al 1955; Moreira 1979; Vohringer 1987)

The GTZ project in Mali (1995) carried out a fertilizer trial with pearl millet where the effects of manure (5t/ha), physic nut press cake (5 t/ha) and mineral fertilizer (100 kg ammonium phosphate and 50 kg urea/ha) on pearl millet were compared.
Pearl millet yields per ha were:
630 kg for control,
815 kg for manure,
1366 for press cake and
1135 kg for mineral fertilizer.
As the costs for mineral fertilizer were higher than those of the press cake, the rentability was US $ 60,- higher for the latter (Henning et al, 1995). The press cake is appreciated by the farmers and can be sold for 10 FCFA per kg (US$ 0.02/kg).

Input for biogas production
The seed cake still contains oil. Hence the seed cake still contains much energy. The cake can in principle be converted into bio-gas by digestion in bio-gas tanks, together with other input materials, such as dung, leaves etc. The biogas can be used for cooking and lighting.
The residue can still be used as organic fertilizer, as it retains all of its minerals and nutrients.
The use of seed cake as a single digestion input has been researched by Foidl et al. (1997) and Diligent/TUE (2005) but requires further investigation.

Input for combustion or charcoal production
Seed cake can be processed into pellets using screw-type presses. These pellets can be used for direct combustion, or they can be converted into charcoal where there is sufficient demand for charcoal, such as in the neighbourhood of large cities where there is a deforestation problem, such as in Tanzania.
No experiments are known so far. Work is done on this topic by Diligent and others.

References Section 1:

1. Heller (1996) - Physic nut - underutilizited species
2. Henning (2004) - The Jatropha System
3. Becker (2004) - Hohenheim - Bio-diesel from Jatropha plantations on degraded land
4. Francis (2005) - A concept for simultaneous wasteland reclamation, fuel production, and socio-economic development in degraded areas in India
5. Gubitz, Mittelbach, Trabi, Graz, Austria, (1998) - Exploitation of the tropical oil seed plant Jatropha curcas L.,
6. Alok Mallick & Nina Sengupta (2005) – Technologies for energy options in remote Indian villages: case studies from Uttaranchal, TamilNadu and Orissa, PowerPoint presentation at JITM Orissa.

Chapter 2: Jatropha planting manual

(main author W. Rijssenbeek)

2.1 Introduction

This manual starts with a general overview of Jatropha agronomy and planting practices. Next, for this manual existing planting data are compiled from different countries over the world. This information has been adapted and edited to make it more accessible. The user of this manual can best use the information of countries with growing conditions similar to his own country, looking at annual rainfall, growing season, elevation above sea level, etc..

Currently we cannot judge correctness of all the recommendations given. E.g. The Indian source does not recommend vegetative propagation, while in general and also for Africa this is seemingly effective as a method. We recommend to look at the best results of Jatropha planting practices under the site conditions (climate and soil) that are most close to that of your site

In case there is no previous experience in your country what so ever, we recommend to start with limited area trials rather than planting 10 or 100 of ha.

It is important to document the Jatropha seed source where possible. The seed source of Jatropha has a substantial influence on the production of seed and oil. Where possible you should try to find out the source of the seed and information on the seeds:

- production performance,
- growth and flowering features,
- oil content,
- genetic decent (have plants been propagated by seeds or cuttings),
- origin (story tellers might give a clue on where the stand originates),
- current site conditions such as climate (rainfall average, seasons, temperature regime, frost occurrence, dew, elevation above sea level, soil type).

Compare the original site conditions (climate and soil type) to conditions at your site, to make a judgment on the viability of the source. One cannot fully predict the adaptability of the Jatropha variety to new conditions. However, selecting seeds from a source with growth conditions similar to yours will give the high chances of success!

2.2 Ecology[1]

Jatropha is a succulent that sheds its leaves during the dry season. It is best adapted to semi-arid conditions[2], where *grassland-savanna (cerrado)*, or *thorn forest scrub and caatingas* vegetation prevail naturally. Its present spread is in the dryer tropics with rainfall from 300 to 1200 mm per annum. Jatropha occurs mainly at low altitudes in the tropics from 0 to 500 m and is adapted to high mean annual temperatures (20 to 28 C in its places of origin). It can withstand slight frost. It is not sensitive for day length.
It performs best on well drained soils with good aeration and is well adapted to soils with low nutrient content. Root formation is reduced in heavy soils. Jatropha does not resist water ponding.

2.3 Agronomy[3]

Germination of the seeds
With good moisture conditions the germination of the seed takes 10 days The seed shell splits and the radicula emerges and four peripheral roots are formed (Soon after the development of the first leaves, the cotyledons wither and fall off.

Flowering
Flowering can commence even during the first year in 5 month after sowing, but this is only under extremely favorable conditions. Normally, flowering follows a longer period of vegetative development. Fruit development takes 90 days, from flowering untill seed maturation.
In regions with a dry and a wet season, flower formation seems to be induced by the onset of the rainy season. It may flower again after having produced fruits, this second round of flowering may lead to another yield if conditions remain favorable for another 90 days. When conditions remain favorable after two generative cycles Jatropha does not respond by another round of flowering but grows vegatively. Reproduction will stop as soon as the dry season begins. In permanently humid regions flowering occurs during the whole year.

Development
Development corresponds to the rainy seasons: vegetative growth occurs during the rainy season, there is little increment or even leaf fall during the dry season.
Plants can gain a height up to 5 m. and reach more than 50 years of age.

Propagation methods
There are various methods of propagation of Jatropha, either generative or vegetative. Each method has a different labor intensity and risk for good establishment.

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1 The general information in this chapter is adapted from Physic Nut, J. Heller, 1996.

2 it is not found in the humid (moist) regions.
3 Idem footnote 2

Generative propagation	Vegetative propagation (cuttings)
• Direct seeding	• Direct planting
• Transplanting of pre-cultivated plants	• Transplanting of pre-cultivated plants
o Seed bed (bare roots)	o Seed bed (bare roots)
o Containers	o Containers

Factors influencing the establishment of the plants for the plantation or hedges are:

Generative propagation
Direct seeding: seeding depth, date and quality of seed, soil moisture content, soil preparation quality.

Transplanting: type and length of pre-cultivation, planting date, moisture content, medium of seedbed/container

Vegetative propagation (cuttings)
Direct planting: cutting material (length, diameter of branch, age, location of the cutting in the tree), cutting time, storage of cuttings, fungicide treatment, planting time, preparation of planting hole, depth of planting, soil moisture content, weed clearance.

Transplanting: type and length of pre-cultivation, planting date, moisture content, medium of seedbed/container

From experience it is clear that in most cases direct seeding has low survival rates. Only under good conditions of a well prepared soil and optimal moisture content and using more seeds per hole (like done in India) direct seeding can be successful.

Good survival rates (>90 %) are given are normally given with direct planting of cuttings and the transplanting methods.

Intercropping
It should be noticed that some authors claim that the root system of cuttings, not having a pen root, but more lateral (side) roots, is less suitable than that of the seeded plants with pen roots in intercropping systems. The side roots make the plants use more space rather than depth. No systematic studies have been done on this feature.

Intercropping with Cassava is not recommended since the plants are both of the same Euphorbia family and Jatropha can be a host for noxious insects and diseases of Cassava.

Pests and Diseases
Jatropha currently seems to have little difficulty with diseases and pests. There might be a number of reasons for this, such as its inherent toxicity for many species, its variation in genetic material and its spread occurrence in the landscape. However, in monoculture some problems might pop up. Hereunder a list is given of most common incidences, prepared by J. Heller 1996, Physic Nut, Promoting the conservation of underutilized and neglected crops.

Name	***Damage and symptoms***	***Source***
Phytophthora spp, Pythium spp, Fusarium spp. etc.	Damping off, root rot	Heller (1992)
Helminthosporium tetramera	Leaf spots	Singh (1983)
Pestalotiopsis paraguarensis	Leaf spots	Singh (1983)
Pestalotiopsis versicolor	Leaf spots	Phillips (1975)
Cercospora Jatropha curcas	Leaf spots	Kar and Das (1987)
Julus sp. (millipede)	Total loss of seedlings	Heller (1992)
Oedaleus senegalensis (locust)	Leaves seedlings	Heller (1992)
Lepidoptera larvae	Galleries in leaves	Heller (1992)
Pinnaspis strachani (cushion scale)	Die-back of branches	Van Harten, pers comm.
Ferrisia virgata (wooly aphid)	Die-back of branches	Van Harten, pers comm.
Calidea dregei (blue bug)	Sucking on fruits	Van Harten, pers comm.
Nezara viridula (green stink bug)	Sucking on fruits	Van Harten, pers comm.
Spodoptera litura	Larval feeding on leaves	Meshram and Joshi (1994)

2.4 India

Adapted from Source: Shri. Vinayakarao Patil,
http://www.mgrbiodiesel.com/statelevl.html

Experience base:

For India based on the trial plantations of Jatropha Curcas in the period 1986 to 2003, the following planting practices are recommended for rain fed conditions.

Climate:

(Tamil Nadu has tropical climate with 600 to 1900 mm precipitation and an average of ca 1000 mm)

Soil type:

All soil types except for water ponding.

Seed origins:

The seeds used as planting material were collected from Maharashtra, Gujarat, Madhya Pradesh & Rajasthan states

Spacing in Jatropha Plantation:

The ideal spacing in Agro-Forestry block plantations under rain-fed conditions should be 3m x 3m. (as the 2,5 x 2,5 m yields a too dense vegetation, affecting seed production)

For single row hedge plantation around boundaries of agricultural fields the spacing should be 2m.

For double row hedge plantation around agricultural fields the spacing should be

3m in each row and distance between two rows should be 1 m and plantation done in a staggered manner.

Size of pits for Planting:

The size of planting pit which should not be less than 0,45 x 0,45 x 0,45 m (1.5′ x 1.5′ x 1.5′). This means that sites where soil depth is less than 0.45m. Jatropha plantations should not be taken up as a commercial crop as the expected returns shall not be available from such sites.

Re-Filling of Pits:

While refilling the pits stones and boulders should be removed and top soil scrapped and mixed with about 0.5 kg. single super phosphate should be added. This operation of refilling of pits should be completed before rainy season (i.e before end of may in Tamil Nadu).

Fertilising:

As a starter gift , mixed with the top soil about 0.5 kg. single super phosphate should be added.

Fertilizer application @ 250 Grams per plant having N.P.K. (15 : 15 : 15) should be repeated at the start of rainy season every year from 2nd year and onwards.

Seed Sowing of Planting Time:

As soon as the rainy season starts 3 seeds should be sown per pit. Singling should be done by end of that season and one healthy plant should be retained and allowed to grow up to next start of the rainy season when it will be ready for cutting back operation.

Pruning and care:

Early in the next rainy season, the one year old plant should be cut back with a sharp cutter at a height of about 0.30m. to 0.45.m. from ground level.

Plant should be allowed to grow and put on side branches up to the beginning of the rainy season of the 2nd year.

Early in the rainy season of the of the 2nd year each side branch should be pruned by cutting 2/3rd top portion and retaining 1/3rd of branch on the plant. This will induce bush formation in an umbrella pattern rather than inducing medium tree like vertical woody growth. The size and shape of the tree so obtained after careful cutting back in the first and pruning in second year in the above explained manner, shall facilitate proper seed production and convenience in harvesting and hand picking of the seed. There should be no compromises on timely cutting and pruning of Jatropha plants to obtain proper production of seed by full utilization of solar energy. Further requirement of periodical pruning should be decided on the basis of further experiments for obtaining optimum production of seed.

Method of planting (direct sowing):

It has been observed that direct seed sowing done at the beginning of the rainy season helps in development of healthy tap root system which grows deep and later spreads out to support the balance of the plant and to enable the plant to utilize moisture conserves deep in the soil. Hence, the site must be kept ready with pits dug before the rainy season.

We do not recommend propagation by cuttings

3 Seeds of Jatropha Curcas should be sown in each pit. But by the end of the rainy season only one plant, which is found to be most vigorous should be retained. The other two plants should be utilized for casualty replacement etc., or rejected.

Management of Jatropha Plantation:

Years	Planting
1st Year	Planting and cutting back, no seed production expected
2nd Year	Maintenance, Protection & Pruning, no seed production expected
3rd Year	Period allowed for establishment and growth of plant, no seed production

	expected
4th Year	Plant expected to be ready to produce seed.

No production of seed should be expected in the first three years.

From 5th year onwards, the seed production starts increasing which stabilizes from 7th year onwards.

Estimated yield and effect of irrigation:

The observation based on the experience of Jatropha growers indicates that the yield of air dried seed is about 300 to 400 kg. per acre or 700 to 1000 kg per hectare on rainfed agricultural lands. The seeds used as planting material were collected from Maharashtra, Gujarat, Madhya Pradesh & Rajasthan states. However, no comparative study has been made about their relative performance.

It has been observed that under irrigated condition Jatropha plants put on heavy vegetative growth but the production of seed is very low. Hence, there is need to undertake further research on these aspects to evolve suitable irrigation pattern or practices to enhance yield under irrigated conditions. Till then it is not advisable to take up irrigated plantation of Jatropha. Similarly it is observed that Jatropha requires sunlight for seed production. Hence it is not recommended for gap plantation in forest areas. Jatropha is ideal for agro-forestry block plantations as well as for hedge row plantations.

The following suggestions are made for further research on Jatropha by the Agricultural Universities in Maharashtra as well as other part of India.

(i) Scope for increasing yield of seed by evolving suitable irrigation practices.

(ii) To select high yielding varieties of seeds.

(iii) To identify varieties having higher percentage of oil content.

(iv) Techniques of reducing gestation period.

(v) Evolving and standardization of appropriate cultivation practices.

(vi) Pruning interval and pruning methodology needs to be perfected for optimum seed production.

2.5 Zimbabwe and Southern Africa

Adapted Source: http://www.jatropha.de/rf-conf1.htm

Climate:

Lowlands are warm and dry with an average rainfall of between 400 and 600 mm, while mountainous regions are wetter with 1500 to 2000 mm average. Experience in Zimbabwe has shown that high rainfall in the relatively cooler parts of the country does not encourage the same vigorous growth. However, in the low-veld areas, such as in the mid-Save region, Jatropha grows well, although comparative yields have not been established. Jatropha does not thrive in wetland conditions. The plant is undemanding in soil type and does not require tillage. In southern Africa, the best time for planting is in the warm season to avoid the cold season since the plants are sensitive to ground frost that may occur in the cold season. (BUN newsletter 1996).

Soil Type:

Although Jatropha is adapted to low fertility sites and alkaline soils, better yields are obtained on poor quality soils if fertilizers containing small amounts of calcium, magnesium, and sulfur are used. Mycorrhizal associations have been observed with Jatropha and are known to aid the plant's growth under conditions where phosphate is limiting. (Jones & Miller, 1992, p.7)

Experience: Considerable plantation of Jatropha had been undertaken in Zimbabwe by a number of active organizations involved in its promotion including the Agricultural Research Trust (ART), the Biomass Users Network (BUN), the Forestry Commission (FC) and the Plant Oil Producers Association (POPA). An estimated four million Jatropha plants have been planted in Zimbabwe by the end of 1997 amounting to nearly 2,000 hectares of plantations.

Spacing in Jatropha Plantation:

Spacing in plantations can range from 2m x 1.5m to 3m x 3mm (Jones N, Miller J.H. 1992, p.7). The number of trees per hectare at planting will range from 1,600 to 2,200. Wider spacing is reported to give larger yields of fruit, 794 kg/ha and 318 g/shrub (Heller J. 1996).

The recommended spacing for hedgerows or soil conservation is 15cm - 25cm x 15cm-25cm in one or two rows respectively. Thus there will be between 4,000 to 6,700 plants per km. for a single hedgerow and double that when two rows are planted.

Fertilising:

For low fertility sites and alkaline soils better yields are obtained on poor quality soils if fertilizers containing small amounts of calcium, magnesium, and sulphur are used.

Diseases and pests:

However, the above uses can be constrained by the prevalence of pests and diseases that attack Jatropha. Existing literature indicates that contrary to popular belief that toxicity and insecticidal properties of J. curcas are a sufficient deterrent for insects that cause economic damage in plantations, several groups of insects have overcome this barrier. The stem borer from the coleopterous family of Cerambycidae that is known as a minor pest in cassava, can kill mature physic nut trees. The relatively few leaf-eating insects present are not capable of doing much damage once the trees have passed the seedling stage. Biological control can make use of beneficial arthropods – polyphagous predators and specialized parasitoids – either by conservation or augmentative releases; the first alternative being the more cost efficient (Grimm & Maes, 1997). In some areas of Zimbabwe the golden flea beetle (Podagrica spp.) can cause harm – eat young leaves and shoots, particularly on young plants. Jatropha is also host to the fungus "frogeye" (Cercospera spp.) common in tobacco.

Method of planting (direct sowing):

Both vegetatively as by direct sowing

Management of Jatropha Plantation:

Estimated yield and effect of irrigation:

In equatorial regions where moisture is not a limiting factor (i.e. continuously wet tropics or under irrigation), Jatropha can bloom and produce fruit all year. A drier climate has been found to improve the oil yields of the seeds, though to withstand times of extreme drought, Jatropha plant will shed leaves in an attempt to conserve moisture which results in somewhat decreased growth. (Jones and Miller, 1992, p.7)

2.6 Zambia

Source: (A guide to the integrated exploitation of the Jatropha Plant in Zambia 2000)

Climate:
Rainfall in Zambia is from 750mm (in southern part) to 1250mm or more a year (northern part)

Soil type:
no wetland area

Seed origin:

Seed sources of Zambia come from Mozambique, Angola and Zimbabwe where the plant is wide spread.

Seed Sowing of Planting Time:

As soon as the rainy season starts 3 seeds should be sown at a depth of 2 to 3 cm. After years or 3 rainy seasons the production of seeds starts.

Spacing in Jatropha Plantation:

The ideal spacing in Agro-Forestry block plantations under rain-fed conditions should be 2,5m x 3.0 m.

Vegetative propagation (cuttings):

Jatropha can be propagated easily from cuttings, which are placed about 20 cm into the soil. The cutting material should be older than one year, already lignified and about 60 to 1.20 m long. The best time of planting is 1 to 2 months before the start of the rainy season, in Zambia in September/October.

For live fencing: just in rows next to each other (spacing e.g. 5 to 10 cm, depending on the desired animal protection, e.g. chicken or goat)), with a planting depth of 20 cm.

Cuttings can be stored for a few weeks, if placed in a shaded area

Chapter 3: Harvesting

Chapter 4: Oil Pressing and Purification

(Main author: Thijs Adriaans)

4.1 Pressing of oil

Basically the process of gaining oil from oilseeds is as old as mankind. Evidence has been found that more than 3000 years ago already oil was pressed from seeds. Although the means that are currently used for this process have evolved, it is still a crushing of the oilseeds that has to be performed.

Different categorizations can be made between the several types of presses. The first categorization is between continuous and discontinuous pressing. An example of discontinuous pressing is found in the kitchen with the garlic press. Also the manual Bielenberg press that is used for e.g. Jatropha is a discontinuous (batch-wise) press. In such a ram press a chamber can be found that is compressed and decompressed in time, and herewith expresses the oil from the seeds and is recharged every cycle. The most well known representative of this category is the Bielenberg ram press, developed by Carl Bielenberg in the mid-1980's. Based on an existing design of a ram press that was expensive, inconvenient and inefficient, Bielenberg made the design of his press that would be cheap, durable, locally maintainable and easy in use. Several hundreds of these presses have been manufactured by local workshops in Tanzania, leading to a good quality for an attractive price and hence good adoption.

Figure 1 – the Bielenberg ram press operated at Kakute Ltd., Tanzania [3]

Figure 2 – close-up of the Bielenberg pressing mechanism. Notice the automatic discharge of the pressing chamber and the stopper in the seed funnel [3]

Nearly all the mechanized presses that can be found on the market use a continuous pressing process. Usually this involves an endless screw that rotates in a cage and continuously kneads and transports the seed material from the entry funnel to a nozzle where pressure is built up. Over the length of the screw the oil is expelled

from the seeds and flows from the side of the screw to a reservoir. At the nozzle the seed material is maximum compressed to a press cake.
Two types of screw presses exist, the 'hole cylinder' type and the 'strainer' type.

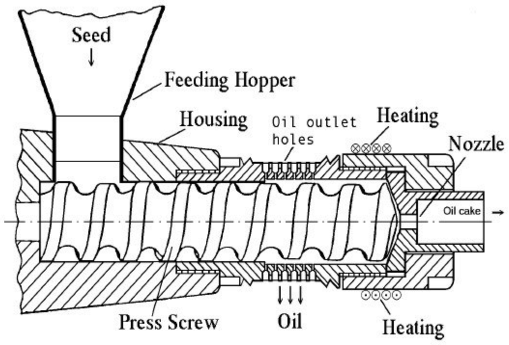

Figure 3 – schematic drawing of hole cylinder type press. Notice the nozzle that can be changed. [2]

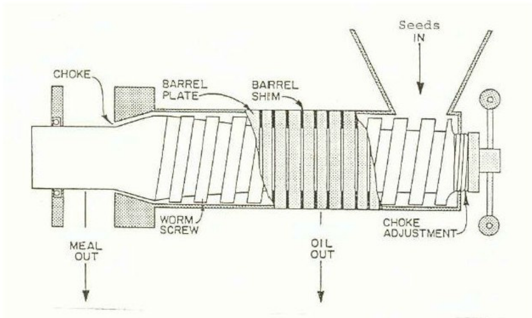

Figure 4 – schematic drawing of the strainer type press. Notice the choke adjustment that is on the opposite side of the choke itself. [2]

In the 'hole cylinder' type the oil outlet is in the form of holes in the press tube. The seed gets a rising compression in the direction of the press head. The oil is pressed out of the seeds near the outlet holes and drained to them. Special perforation in the tube avoid turning of the press cake/seed-mix with the screw. Otherwise, there would be no forward movement. The press cake is pressed through changeable nozzles and formed to pellets. In most types of presses the nozzle is heated to avoid blocking of the press cake. Hole cylinder type presses exist for small capacities (up to approximately 100 kg/h seed). For different types of oilseeds the press can be adjusted by changing the nozzle diameters and screw rotation speed. The hole cylinder type press is easier to clean and to adjust than the strainer type press.
The strainer type press has its oil output in the form of strainers. The strainers are built up in the form of bars, and their interspacing (gaps) is adjustable. Mostly the whole press tube consists of the strainer. The diameter of the screw increases over the length to get a rising compression of the seed. Sections with changing diameter can be found several times on the screw. During the flow of the seed through the press, the oil is drained via the strainer, which surrounds the pressing space. The choke size can be adjusted to press the seed harder. For several oil seeds it is necessary to change the gap size of the strainer bars (interspacing) where the oil comes out, to get an optimal yield of vegetable oil. At some types of strainer presses it is possible to change segments at the worm screw in order to change the compression of the seed. Other manufacturers offer extra screws. In addition the choke size and the rotation speed should be adjusted when pressing different kinds of seed. Strainer presses exist in a wide capacity range from approximately 15 to 2000 kg/h of seed. The press cake comes out of the choke formed as flat plates.

Figure 5 – The Danish BT press is an example of a hole cylinder type press. Notice the nozzle, left in front. [4]

Figure 6 – The Sundhara oil expeller is a representative of the strainer type presses. On the right side the choke adjustment. [3]

To press oilseeds a considerable amount of power is needed. Small presses like the Bielenberg ram press can be powered by hand, by one or several operators. Capacity is then typically 1-10 kg/h of seeds. Larger capacity presses, especially the screw presses, are powered by engines. Mostly electrical engines are chosen because of their ease of installation, coupling and operation and low cost. It is, although, perfectly possible to couple the press directly to a diesel engine to be independent of grid – the diesel engine can even run on the oil that it is pressing itself.
For the required power an estimated value of 0,06 – 0,1 kW per kg/h of seed can be calculated with.
Many hole cylinder models provide heating of the nozzle, and sometimes the seed is preheated before pressing. It is observed that heated material flows better (this holds for cake and oil) but care has to be taken to prevent overheating and degradation of the oil. Generally 60 °C can be regarded as a safe maximum. Above this temperature too much phosphorus from the cell wall may be pressed into the oil, leading to off-spec oil, and in extreme cases the oil may be damaged (cracked) by very high temperatures (above 150 °C).

Suggested models

Below are some examples of presses that can be bought readily on the market.

	Manufacturer	**Model**	**Capacity**	**Price**	**Website**
TZ	Vyahumu Trust	Sayari Expeller	15-33 liters/hr (380V engine)	TSh 3,2M (€ 2300)	www.jatropha.de/tanzania/expeller.htm
SE	Skeppsta Maskin AB	Täby T40	2-4 liters/hr (380V engine)	SEK 22.000 (€ 2350)	www.oilpress.com
DK	BT Maskinfabrik	BT50	5-8 liters/hr (230V	DKK 26.000 (€ 3750)	www.bt-maskinfabrik.dk

			engine)		
D	IBG Monforts	Komet S120F	15-33 liters/hr (380V engine)	€ 21.475	www.oekotec.ibg-monforts.de

4.2 Purification of vegetable oil [2]

After pressing vegetable oil contains 1-13% solids by weight. The solids can be separated from the oil by means of sedimentation, filtration or centrifugation, or a combination of these processes. Before technical use the oil should be clean of all particles > 5 µm. The cleaning process should follow shortly after the pressing process to avoid filtration problems when the oil was stored under unfavorable storage conditions (see Production and handling criteria).

Sedimentation
Sedimentation is the simplest and cheapest way of cleaning by using the earth's gravity: the solids settle at the bottom of the tank. Sedimentation is only recommended for small processing capacities of about one tonne of seed per day. It is a cheap cleaning method because no hardware has to be purchased, only a storage tank large enough to keep the oil about a week with little or no flow.

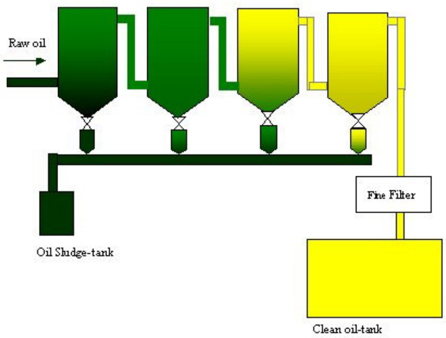

Figure 7 – example flow diagram of a sedimentation system [2]

Disadvantages of the sedimentation system are that only under optimal conditions particles from 8 µm can be separated, which means that a security filter (bag filter or fine filter) has to be used, and the relatively high loss of oil in the sediment. Both filtration and centrifugation give more oil yield after the purification.

Centrifugation

Using centrifugation force for particle separation is much faster than sedimentation. Both decanters and separators are industrial devices that work according to this principle. Important parameters are the solids content in the oil, size of the particles and viscosity of the oil. As centrifugation hardware is relatively expensive for a small scale, there is little experience with these devices.

Figure 8 – example of a centrifugation system with a bag filter as a security. [5]

Filtration

The basic principle of filtration is blocking any particles in the oil against a membrane. The easiest way of filtering is using a cloth. Attention, not every textile has a suitable pore size! Consider the purchase of special filtering cloth, like Monopoel (D) offers. The cloth is available in sheets (see picture below) or as bags, for example.

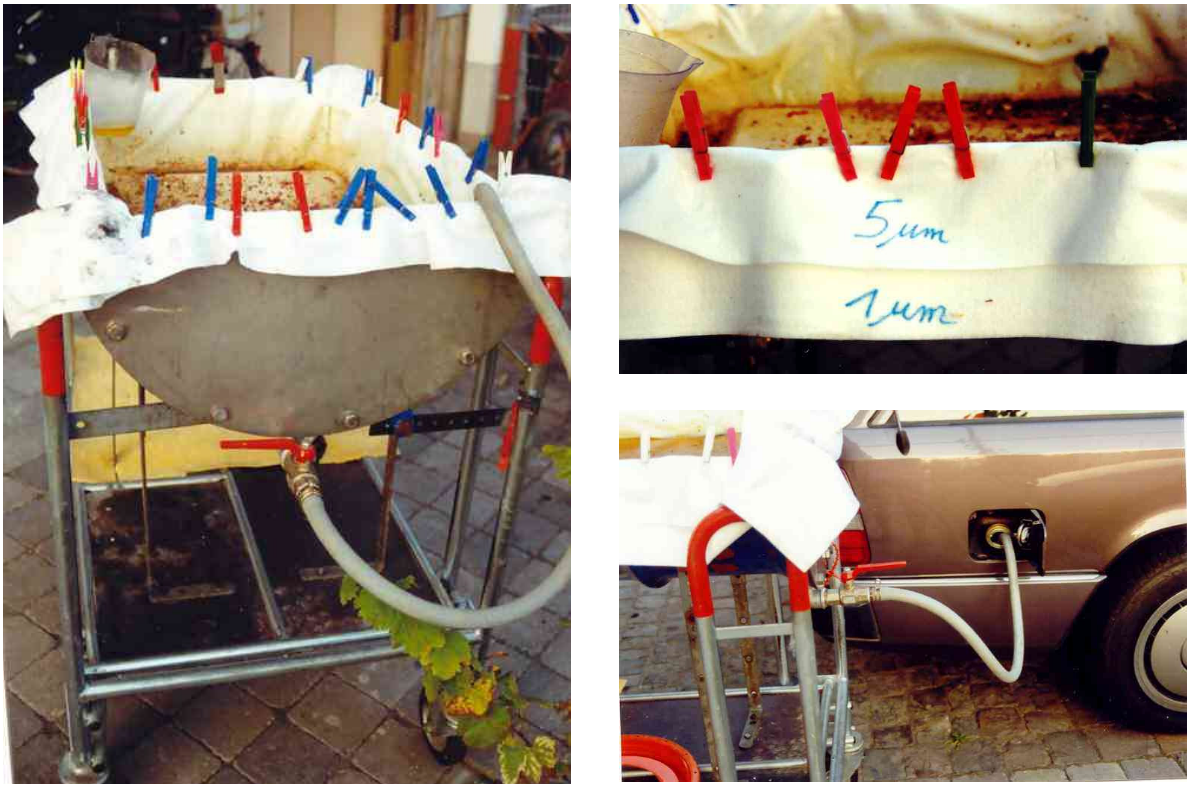

Figure 9 – PPO filtration (in this case used cooking oil) on the site of Monopoel, http://www.monopoel.de/stammseiten/eigenes_altp.html. In this case two clothes are used but that is not necessary, one 1 µm cloth is sufficient.

Using filter cloth in home made devices can give very good filtering results. As the filtering processes is not pressurized, purification is very good but speed is low. For home users and small factories (up to some liters per hour) this can be an attractive low-cost option as the process can run unattended without purchasing special hardware. It is recommended to sediment the oil for some days before filtering to avoid short changing interval of the filter cloth.

If filter hardware is used, like a plate, cricket or leaf filter, often the membrane pore diameter is chosen larger than the desired oil quality. This kind of filters has to be used for some time in a closed-loop situation to build up a layer of particles (cake) against the membrane. Herewith a finer final filtration is provided. Plate filters are flexible and can be extended by adding more frames for bigger capacities. They are widely applied in the food industry. Filter cake discharging can be manual or automatic. Manual cake discharge takes about half an hour per day. The following key numbers hold for rapeseed oil: oil content in the filter cake of about 35-50% and 2-4 kg of filter cake after processing 100 kg of rapeseed.

4.3 Quality aspects [2]

For use rapeseed oil as a fuel in Europe a quality standard has been developed that contains the characteristics of the oil that are important and their limit values. As can be seen in the diagram below, DIN standards document the exact procedure of determination of the properties. A distinction is made between two kinds of properties, the characteristic ones that depend on the oil seed used, and the variable ones that depend on the processing used (pressing, filtering, after treatment, etc.) Although this standard has been developed for rapeseed oil, the limiting values also hold for other oils because they are mostly related to the use of the oil in engines. This is especially true for the 'variable' properties. The characteristic properties for jatropha oil differ from those for rapeseed oil, but that is nothing to worry about, since they cannot be influenced by the processing anyhow. It has been proven widely that jatropha oil is as good an engine fuel as rapeseed oil is.

LTV-Work-Session on Decentral Vegetable Oil Production, Weihenstephan

Quality Standard for Rapeseed Oil as a Fuel (RK-Qualitätsstandard)

05/2000

in Cooperation with:

Properties / Contents	Unit	Limiting Value min.	Limiting Value max.	Testing Method
charcteristic properties for Rapeseed Oil				
Density (15 °C)	kg/m³	900	930	DIN EN ISO 3675 DIN EN ISO 12185
Flash Point by P.-M.	°C	220		DIN EN 22719
Calorific Value	kJ/kg	35000		DIN 51900-3
Kinematic Viscosity (40 °C)	mm²/s		38	DIN EN ISO 3104
Low Temperature Behaviour				Rotational Viscometer (testing conditions will be developed)
Cetane Number				Testing method will be reviewed
Carbon Residue	Mass-%		0.40	DIN EN ISO 10370
Iodine Number	g/100 g	100	120	DIN 53241-1
Sulphur Content	mg/kg		20	ASTM D5453-93
variable properties				
Contamination	mg/kg		25	DIN EN 12662
Acid Value	mg KOH/g		2.0	DIN EN ISO 660
Oxidation Stability (110 °C)	h	5.0		ISO 6886
Phosphorus Content	mg/kg		15	ASTM D3231-99
Ash Content	Mass-%		0.01	DIN EN ISO 6245
Water Content	Mass-%		0.075	pr EN ISO 12937

Figure 10 – the so-called Weihenstephan or RK2000 standard summarizes the criteria that determine the quality of PPO as an engine fuel. [2]

Production and handling criteria

To make sure the properties of the oil are within the desirable range, several things have to be kept in mind. The variable properties are briefly discussed, together with their consequences for the production process.

- **Contamination**: this describes how much foreign material (particles) may be present in the oil. Of course this parameter is directly influenced by the purification process. The contamination value determines the lifetime of the engine's fuel filter.
- **Acid value**: this is a measurement of the content of free fatty acids in the oil. Free fatty acids give rise to degradation of the oil (it gets 'rancid') and the components in contact with it (oxidation). Their formation is mostly caused by bad storage conditions, i.e. contact with air, exposure to sunlight, heat etc.
- **Oxidation stability**: the oil quality should not degrade in a hot environment. This is because the fuel is exposed to high temperatures when it is in use. The mechanisms are the same as explained under 'Acid value'.
- **Phosphorus content**: in cold pressing most of the phosphorus that is present in the seed, goes into the press cake and not into the oil. That is desired

because phosporus (especially phospholipids) gives rise to blocking of the engine's fuel filter and to oxidation of the combustion chamber because phosphorus is a strong oxidator at high temperatures.
- **Ash content**: the ash content reflects the amount of material that remains unburnt after combustion of the oil in the engine. Mostly this material is salts present in the oil. It can be kept low by gentle pressing and good filtering.
- **Water content**: the plant material contains some percents of water. In the oil the water content should be limited, because water causes the fuel filter material to swell and hence block and water causes oxidation inside the injection equipment.

A number of guidelines are summarized below.
For plant oil storage, the following conditions are favourable:
- Low total impurities in the oil
- Cool storage temperature
- Avoiding temperature variations (and hence water condensation)
- Darkness
- Contact with fresh air
- Easy to clean tanks

Literature

1. Meeting a Pressing Need, Project Appraisal of the Oilseed Ram Press and Approaches to Implementation – A. Hynd and A. Smith, Design for Developing Countries, 2004
2. Equipment for decentralised cold pressing of oil seeds – N. Ansø and E. Ferchau, Folkecenter, 2000
3. Archive Kakute/Diligent Tanzania Ltd., 2004
4. Archive Diligent Energy Systems BV, 2005
5. Archive Dajolka, Niels Ansø, 2005

Chapter 5 Use of Jatropha products

(Main author Thijs Adriaans)

Jatropha curcas is such a promising species because many products from the plant can be made useful. Primarily the oil from the seeds, but other products must not be forgotten to make the whole use as profitable as possible.

5.1 Applications of oil

Lamps and cook stoves

The oil can be used to fuel cook stoves and oil lamps [1]. As the properties differ considerably from those of lamp oil or kerosene, a modified design of these utensils has to be adopted. In the case of oil lamps this means, for example, that the wick has to be short so the flame is immediately above the liquid surface. More about this and suitable lamp designs can be found in the 'Lighting' section at Reinhard Henning's site of The Jatropha System, http://www.jatropha.de/lamps/index.html. Modified cooking stoves for plant oil have also been developed, although this research has not been completed either. These stoves resemble petrol burners as they work with pressurized liquid fuel. Many designs and important considerations are to be read on http://www.jatropha.de/cooker/index.html, the 'Cooking' section of the same website.

Feedstock for soap production

It is fairly easy to produce soap from vegetable oil [2]. Technically spoken the triglycerides of the plant oil are converted to salts of metal ions (natrium, potassium) and fatty acids (stearate, palmitate). The components necessary for soap making, and their ratios, are 1 liter of plant oil, 0,75 liter of water and 150 g of caustic soda per liter of oil. Adding less water gives a harder soap, adding more water requires addition of flour or starch to get a consistence that is solid enough. As the ingredients are relatively cheap and the soap can generally be sold at a good price, soap making can be an attractive option. The outline of the recipe is as follows:

- Prepare a solution of the caustic soda by dissolving the soda into the water (never mix these components the other way around – risk of burning!)
- Stir until everything has dissolved. The bowl will get hot, cool it using cold water at the outside, or just let it cool down for a while.
- Pour the oil into a bowl and put it beside the bowl of caustic soda solution.
- Pour the caustic soda solution slowly into the oil, stirring all the time. Immediately the mixture will go white and soon it becomes creamy.
- Continue stirring until the mixture is like mayonnaise. This is the moment to add additives like glycerin, perfume etc.
- If the mixture is still creamy, pour it into a mould, where it can harden overnight. The moulds can be made from a wooden tray or a cardboard box, lined with a plastic sheet. Alternatively, consider using convenient and attractive shapes like small plastic bowls.
- The mixture hardens overnight in tropical temperatures, or in several days in temperate regions. Then it can be released from the mould and cut if necessary. For good sale and use the pieces of soap should not be larger than 150 gram or 6 to 8 to 2 cm.

- Even after this first hardening the soap continues to mature for some time. It should be stored for some two weeks on shelf before sale.
- Wrapping the soap into a nice paper or clear plastic will add greatly to its sales value!
- Last but not least, don't forget to clean all the used utensils properly, as caustic soda is rather aggressive and Jatropha PPO is toxic.

Direct fuel for engines – PPO

Straight vegetable oil (or Pure Plant Oil, PPO) is a very suitable fuel for diesel engines. Unfortunately most contemporary diesel engines have evolved so far to the use of fossil diesel fuel that more or less decisive adaptations will be necessary to run these engines successfully with PPO for a longer period. The luck, on the other hand, is that most diesel engines that are in use in developing countries still rely on older technology. Hence the use of PPO with little or no modification is often possible.

Prechamber engines

The most important distinction that has to be made, is between direct injected engines and prechamber engines. The first category is generally more sensitive to its fuel and operating conditions and should not be run with vegetable oil or blends without adaptations.

The second category of indirect injected engines is less sensitive. In these engines the fuel is not atomized into the combustion chamber itself, but into a small prechamber. Here combustion starts and the burning gases rush through the connecting channel into the actual combustion chamber above the piston. As the combustion starts in a concentrated way in the very hot prechamber, the fuel's nature and quality are not of so much importance. Depending on the environment (temperature), the type of PPO (rapeseed, jatropha or thicker like palm or castor) and the usage of the engine it may be possible to switch to PPO without conversion of the engine. The warmer the environment, the thinner the oil and the more continuous the usage of the engine, the better it is possible to use PPO. A good strategy to discover the possibilities of your setup is to gradually increase the amount of PPO in the mix with diesel. Of course a good overall condition of the engine (compression, injector wear) is required, as PPO generally has higher requirements than diesel. Start with about 25% PPO, 75% diesel, and if successful, increase the PPO fraction in the next tank filling. If the engine begins to give starting difficulties or the full power is no longer developed, then you reached the maximum percentage of PPO for the current configuration. Especially the last percents of diesel make the largest difference.

Conversion of the engine is meant to overcome three major differences between PPO and diesel:

- PPO is more viscous (thicker) than diesel at moderate temperatures
- Under similar conditions PPO burns slower (has a larger ignition delay) than diesel
- It is more difficult with PPO than with diesel to get a complete combustion

The first problem is mainly an issue in temperate climates or with very viscous oil, like palm oil or castor (mamona) oil. It mainly affects the flow resistance in the fuel system until the injection pump. The majority of diesel fuel systems are suction systems, driven by the injection pump. If the pump cannot overcome the resistance, the engine won't get enough fuel and will refuse to accelerate. The flow resistance can be overcome by heating the PPO to make it less viscous. Heating with hot

coolant is the best option, because coolant is water (or water based) and hence it can deliver a lot of heat, and second because the coolant water has the ideal temperature of close to 100 °C. Heating the PPO with heat from the exhaust may seem attractive (or it can be the only option, in air cooled engines) but has the large danger of temperature going too high, causing the PPO to crack chemically (above 150 °C). Other options that should be considered to reduce the flow resistance are placing the tank in a warm location (in case of a stationary engine) and increasing the fuel line diameter. In European PPO conversions the supply line diameter is changed from 6 to 8 mm or more.
To overcome the second and third issue it is important that the injectors are in proper condition. These parts make sure the fuel is atomized (sprayed into very fine droplets) for combustion. In case of prechamber car engines in Europe the guideline is kept that the opening pressure of the injector (reflecting its condition) should be checked after 100.000 km. If no special PPO injectors (like offered by Elsbett) are installed, it is advised to increase the opening pressure of the new injectors by 10-20 bar and to advance the injection timing of the engine a bit. Engine specialists are able to adjust the engine timing auditively, i.e. the converted engine should give the same combustion sound on PPO as it did with diesel. If it should remain possible to drive the engine with pure diesel at high loads after conversion, it is recommended not to advance the timing too much, to avoid hard knocking.
For a proper cold start with PPO the preglowing system (if available) should be in good working order. It is advisory to double the preglowing time (manually or by adjustment). Eventually longer or more robust glow plugs can be installed. To minimize cold start emissions, some afterglowing is useful.

Direct injection engines

The same that is written above also holds for direct injected (DI) engines. But as the fuel injection is done immediately on top of the piston, into the relatively cold combustion chamber, the DI engine has more prerequisites towards conversion. Even more than prechamber engines, DI engines come with a variety of pump concepts. The line pump and distributor (rotary) pump are least problematic in conversion, as they are often quite tough. Attention should be paid if your engine has a distributor pump manufactured by Lucas/CAV, Delphi, Stanadyne or Roto-Diesel. Because of their construction these pumps are less suited for PPO. Usually distributor pumps of brand Bosch, Diesel-Kiki, Nippon-Denso or Zexel are more robust. Line pumps are always of strong construction and can handle cold PPO. In unconverted DI engines of these types it is not recommended to try blends of more than 30% PPO. More modern types of DI engines (say, last ten years) may be equipped with common rail injection or unit injector systems. These systems contain rather sensitive (and precious) high tech and are always computer controlled. Both these are reasons not to try experiments with PPO in these engines, unless you know very well what you are doing.
It is common practice to convert DI engines with a two-tank system. A small tank is added to contain diesel for cold starting and the warm engine can be switched to PPO from the main tank. In this way the cold start phase with PPO, which is the most critical phase, is avoided. For the rest the conversion resembles that of a prechamber engine. A general layout for conversion with two tanks looks like this:

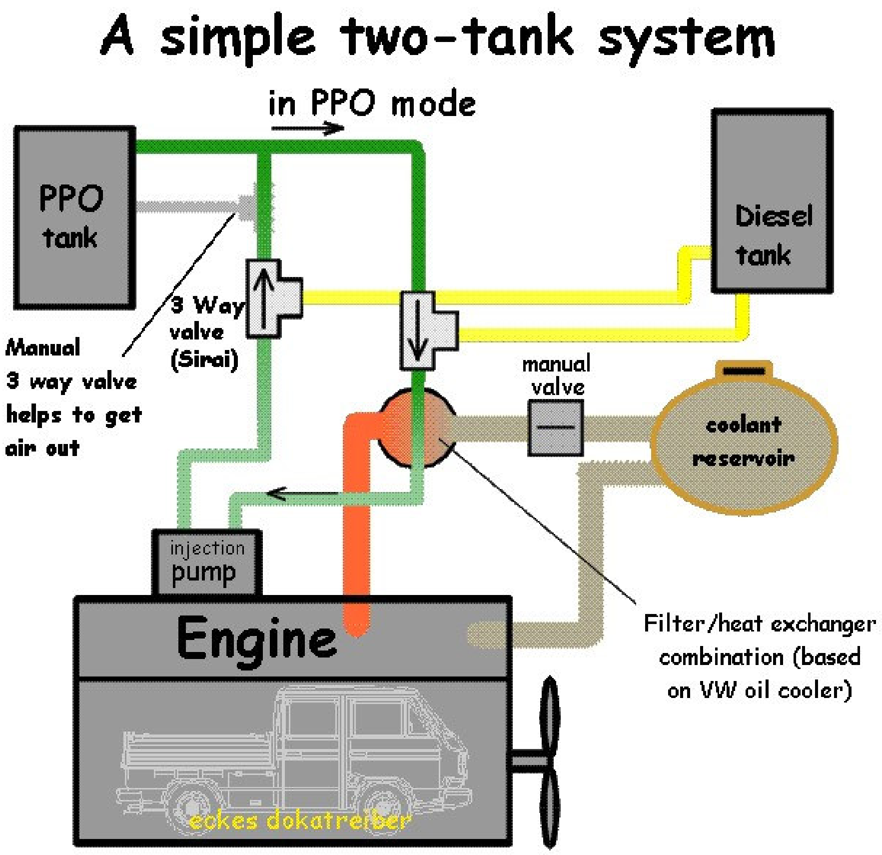

Figure X – Schematic layout of a two-tank system [3]. The car is started using diesel (yellow lines). In normal use PPO is taken (green lines). All fuel is heated with coolant (red/grey circuit), in this case using a former oil cooler from Volkswagen: cheap, easy and powerful heat transfer. Based on this schematic design many variants can be thought of for specific purposes.

Even after conversion it is good to remain careful with the engine until experience has taught how it behaves with PPO. Like with the prechamber engine it is advised to increase the PPO percentage in steps and only to increase to a higher PPO content if the engine completed the previous step successfully. That means it has to run like it did before, sound homogeneously and start like it did before conversion. If the engine emits smoke more than occasionally it's good to search for a reason: grey smoke at full load means too much fuel, too little air or contamination in the combustion chamber. Blue smoke means oil consumption, maybe caused by coking of the oil springs around the piston. Grey smoke at idle means incomplete combustion because of worn injectors or too little compression.
It is very important to keep an eye on the engine oil. Consumed volume of oil has to be added. The replacement intervals of the engine oil should be shorted (to half or two thirds of the original length) because the oil is much more stressed with PPO as a fuel, especially if the engine is used for short runs or with very high load. It is especially important to be keen on a rising oil level, as this indicates that the lubrication oil is diluted with PPO. If this happens, the oil should be changed fast and the cause of the dilution has to be solved. This cause can be, for example, a lot of cold operation of the engine, a lot of low-load operation (especially running idle) or a bad injector. The sentence above already indicates that DI engines don't like running at idle for prolonged periods. Then it is better to switch the engine off and on again.

Feedstock for biodiesel production

Instead of adapting the engine to run on PPO, the oil can also be chemically treated to produce biodiesel. Properties of biodiesel are very similar to those of fossil diesel, and hence it can be used in any diesel engine without adaptations. Disadvantages to the user are its slightly lower energy content, leading to an increase in fuel consumption of about 2-10%, and the fact that it works as a solvent. Biodiesel tends to clean the fuel system, taking the dirt that has been gathered during diesel use, and herewith it may cause blocking of the fuel filter. Furthermore its solvent nature may affect the integrity of the fuel lines and gaskets in the fuel system.
The production of biodiesel is essentially a simple chemical process. The vegetable oil molecules (triglycerides) are cut to pieces and connected to alcohol (methanol or ethanol) molecules to form methyl or ethyl esters. As a side product glycerin is formed. The reaction looks like this:

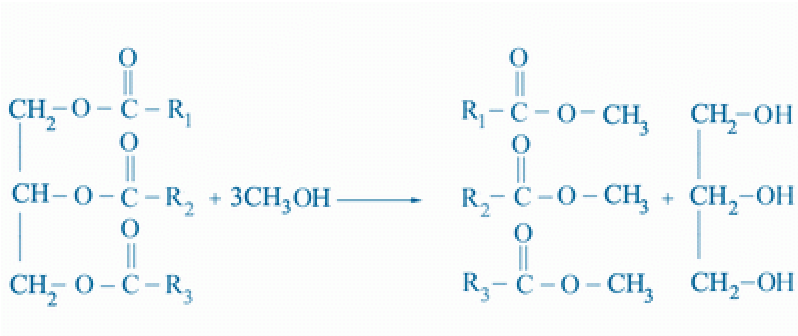

Figure X – Molecular representation of the biodiesel production process. On the left is a PPO molecule (triglyceride). Three molecules of methanol are added. The triglyceride molecule is broken into its three fatty acids (recognized from their R group, typically 16 to 18 carbon atoms long) and these fatty acids combine with the methanol to form methyl esters. On the right most side, the side product glycerin can be seen.

As an alcohol for the reaction usually methanol is used, made from natural gas or crude oil. Theoretically ethanol could be used as well, with the advantage that it can easily be produced in a biological way, for example by fermentation. The use of ethanol is connected to three disadvantages:

- Ethanol is more expensive than methanol. But home made ethanol would be cheaper.
- The esterification process with methanol is a lot more straight-forward and easy than with ethanol. One of the problems is that the ethanol must be free of water (anhydrous) which is not easily accomplished in a non-industrial setting. Distillation alone is not enough, as it only yields 95% pure ethanol at max. The Journey to Forever website documents why ethyl ester production is such a hassle.
- The properties of methyl esters are more favourable than those of ethyl esters. Especially the cold-related properties like CFPP and viscosity lag behind. Although these are not of such importance in tropical climates, the author would personally choose to convert the engine to SVO instead of going through the hassle of producing ethyl ester while its gain in properties is so marginal.

For these reasons only the use of methanol is considered in the remainder.

Biodiesel production recipe
Generally this recipe can be followed to produce biodiesel from fresh PPO and methanol in a base catalyzed environment. The recipe below is a very much summarized general guideline. Many tips and tricks and safety recommendations have been left out for the sake of compactness. It is good to read more about this before starting. If you would like to use used cooking oil, ethanol or another catalyst instead, many Internet sites can help you adapt the recipe. Please notice that the methanol and lye involved are quite dangerous chemicals. Be sure to know what you are doing, work in a well ventilated area and wear protective clothes and glasses!
The following resources are required (all quantities are expressed per liter of PPO): 1 liter of PPO, the younger the better; 5 grams of lye (caustic soda; NaOH (> 95%) or KOH (> 85%)); at least 220 ml of methanol (> 99%).
First dissolve the lye into the methanol. Shake or swirl until all the lye has dissolved. This may take 10 minutes. It is normal that temperature rises. This mixture is called sodium methoxide. Now make sure the PPO is in a vessel large enough (at least 150% of its volume), preferably with a valve at the bottom, and heat it to about 60 °C, then stop heating. Then add the methoxide mixture and make sure it is mixed well for at least 10 minutes. Leave the vessel and let the different constituents separate by sedimentation. The glycerin will settle out at the bottom. After 8 to 24 hours the sedimentation is complete and the glycerine can be drained off. What remains is raw biodiesel. If the reaction went well and the biodiesel is clear, it may be used straight, although its quality may be inferior because of impurities. Water washing will remove most of these impurities. Consult any of the websites listed below to gather more information about this.

5.2 Applications of other Jatropha products

Press cake
When the nuts are pressed to oil, about 20-30% of oil is gained. The rest remains as press cake. Not only are all the minerals still inside this cake (PPO contains virtually no minerals) but due to the oil content the press cake still contains a considerable amount of energy. With its 20-25 MJ/kg it's about half as energy-rich as the oil that contains 40 MJ/kg – but the fact that there is two to four times more presscake, compensates. The theoretically best use of the press cake is first for energy purposes and then as a fertilizer. Energy use leaves the nutritional value intact, and use as a fertilizer implies that the calorific value is lost.

Press cake for biogas

Press cake as a biogas generation feedstock
Press cake as briquettes for fuel
Press cake as a fertilizer
Wooden stems
Leafs
Insecticide from oil and/or press cake

Literature

[1] Web site 'The Jatropha System', Reinhard Henning, Bagani, http://www.jatropha.de/
[2] Henning (2001) - Manual for Jatropha curcas L in Zambia

[3] Web site 'Eckes Dokatreiber', http://www.poeltech.de/rpm/
[4] Web site 'Journey to Forever', http://www.journeytoforever.org/biodiesel.html
[5] Web site Bioking, http://www.bioking.nl/zelf_biodiesel_maken.htm

Chapter 6 Implementation

6.1 Production models

6.2 Financial models to introduce Jatropha with farmers

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6.2.1 Introduction

Jatropha is a special crop for several reasons: firstly it is a new (cash) crop for many regions, secondly it is a perennial crop that takes several years to become fully productive and thirdly its price development is uncertain because it competes directly with the highly volatile oil market. These characteristics make that special attention should be given to the way the introduction is financed. In this section an effort has been made to describe three standard models to finance the Jatropha introduction among farmers. The three models are:

(a) Buying agreement between promoter and farmer
(b) Joint venture between promoter and farmer
(c) Loan from promoter to farmer

Obviously, choosing a finance model is highly dependent on the local context. The models described in the following should therefore be considered as standards that must be adjusted to fit the characteristics of the farmers and their environment.

In order to be able to compare the models, the following assumptions have been made for all models:

- The Jatropha plant starts producing from year 3 onwards
- The promoter of the system is also (co-)owner of the oil processing facility (press)
- Promotor has sufficient demand to sell all oil produced

While the following models all depart from the assumption that the promoting institution is involved in the processing facility, one can also think of a scheme in which this facility is community owned. In this case loans are issued to a local entrepreneurial group (preferably women) who own and operate the processing facility. Farmers bring their Jatropha fruits to be pressed, pay for the service but remain owner of the oil and press cake. The oil produced can be used by the farmers themselves (fuel for mills, vehicles, pumps, oil lamps etc.) or sold to others. The processing enterprise may or may not be engaged in the marketing of the marketing of the oil and press cake.

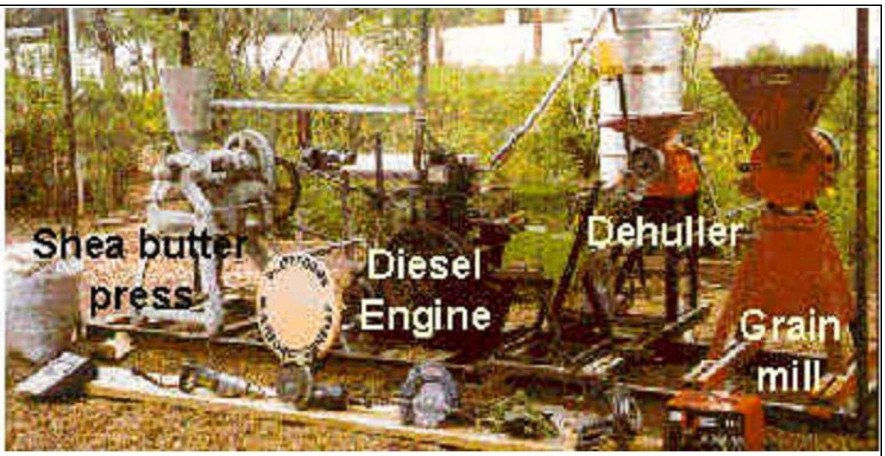
An example of the above are the *Multi task energy platforms*[4] that function in Mali. A village based press equipment is managed by a cooperative group of female entrepreneurs and used to produce oil for Jatropha farmers. Part of the oil is used by the platform itself to give power to a cereal mill, a battery charger, electricity

[4] See, amongst others, http://www.malifolkecenter.org/

generation etc. In this way a service is provided to the community and local employment and income is generated.

It is clear that the ownership of the initiative is to be passed on to local economic agents as much and as soon as possible. so there is a direct economic incentive to continue the activities, also after the promoter has left the intervention area. However, in a start-up phase it may be necessary for the promoting institution to participate financially in the processing facility.

The following financing models will focus mainly on the role a promoting institution can play in stimulating farmers to invest in Jatropha plantations.



A Multi Functional Platform in Mali (MFP)

6.2.2 Buy-back agreement at fixed price

In this model farmers contribute their land and labor, while the promoter contributes seeds, initial fertilizer and technical assistance. All contributions are in kind so no money flows take place between the promoter and the farmer until year 3, when the farmers sell their first Jatropha beans to the promoter. The press cake is preferably returned to the farmers, in order to close the production cycle as much as possible.

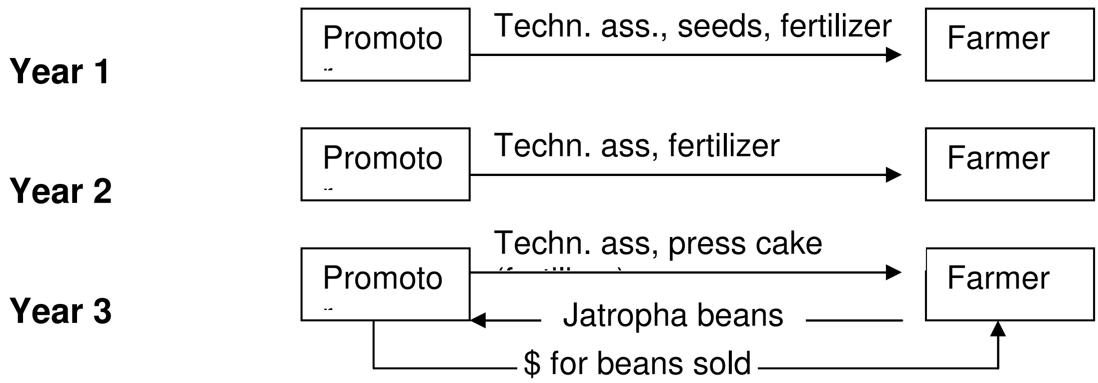
Input	**Year 1**		**Year 2**		**Year 3**	
	Contribution of		Contribution		Contribution	
	Promotor	Farmer	Promotor	Farmer	Promotor	Farmer
Land		X		X		X
Labour		X		X		X
Seed	X					
Fertilizer	X		X			X
Techn. Ass.	X		X		X	
Output	**Year 1**		**Year 2**		**Year 3**	
	Income for		Income for		Income for	
	Promotor	Farmer	Promotor	Farmer	Promotor	Farmer
Beans						X(1)
Oil					X	
Press cake						X(2)

Notes:

(1) Preferably the promoter signs an agreement with the farmers in which:
- the farmer agree to sell all its production to the promoter; and
- the promoters agrees to buy all the production of the farmers at a fixed price per kg.

(2) The press cake will be returned to the farmers, to be used as fertilizer for their jatropha plants or other crops or simply to sell. The cake has a value that will be deducted from the beans price. If farmers are not interested in the press cake, the promoter may sell it as manure to external clients.

The following flows take place during the first three years.



The advantages of this model are:

- Its simplicity: no financial flows take place until year 3. This is useful when working with a large number of small farmers.
- Risk for the farmer is small: the promoter guarantees to buy at a fixed price any quantity produced.
- Subsistence farmers, who are often resistant to loans, may find this an acceptable model.

The disadvantages are:
- Risk lays mainly with the promoter;
- There is no compensation for the work of the farmers during the first 2 years;
- Farmers may not have a clear idea of the market price of their product.

The buying and price guarantee can only be given if there is an economically viable press facility operating. This is only possible if sufficient production volume is supplied.

6.2.3 Joint venture

In this model, the promoter and farmers sign an agreement in which the results of the investment (beans, oil, press cake and the income generated with their sale) are distributed among the investors, according to their respective contribution. In order to do this, the contribution of the parties involved has to be valued. In the following a numeric example will be presented (numbers are ficticious).

Input	**Year 1**		**Year 2**		**Year 3**		**Total**	
	Contribution of		Contribution		Contribution			
	Promotor	Farmer	Promotor	Farmer	Promoter	Farmer	Promotor	Farmer
Land		1		1		1		3
Labour		10		5		5		20
Seed	1						1	
Fertilizer	3	7	3	7	3	8	9	22
Techn.	donation		donation			donation		
Ass.					30	15	30	15
Processor								
Total	**4**	**18**	**3**	**13**	**33**	**29**	**40**	**60**
Output	**Year 1**		**Year 2**		**Year 3**		**Total**	
	Income for		Income for		Income for			
	Promotor	Farmer	Promotor	Farmer	Promotor	Farmer	Promotor	Farmer
Beans								
Oil					30	45	30	45
Press					10	15	10	15
cake								
Total					**40**	**60**	**40**	**60**

Technical assistance is considered a donation in this example. During the introduction phase (in which many uncertainties still exist), it is recommendable that the technical assistance is provided free of charge. In the expansion phase, technical assistance may be in included in the promoter's contribution, especially in the case of commercial (= non-subsistence) farmers.

The advantages of this model are:

- Risk is more equally shared between farmers and promoter
- More interesting for farmers with entrepreneurial spirit because possible rewards are higher.

The disadvantages are:

- More intensive in-field follow-up is necessary in order to prevent farmers from reporting less harvest than they actually have. This risk is less eminent if the promoter is the only buyer of Jatropha beans in the region.
- Administratively more complex than model 1.
- There is no compensation for the work of the farmers during the first 2 years.

Factors that may contribute to successful Jatropha joint ventures:

- Clear and enforceable contracts
- Strict follow-up during the growing process
- Significant and well-balanced contribution of all parties involved

6.2.4 Loans

In this model, the promoter issues loans to the farmers. The loans should preferably be limited to inputs (seeds and fertilizer), while farmers contribute land and labor. Also a grace period of at least 2 years should be considered, until the plantation becomes productive. In two cases loans for labor may be considered:

- Subsistence farmers who replace other (less rewarding) crops for Jatropha. This transition may result in a temporary decrease of their income until the Jatropha plantation becomes fully productive.
- Commercial farmers who contract external labor.

The difference between model 1 and 3 is that in model 1 there is a fixed price per kg in which all the costs of inputs are included. It is not clear to the farmer what the actual market price of the seeds is. In model 3 the inputs are valued at their real value and an interest rate is charged to cover the administrative and financial cost. Another important difference is that in case of a bad harvest in model 1 the farmer will only lose his invested labor, while in model 3 the farmer will, on top of this loss, have to pay his (seed and fertilizer) debt.

The advantages of the loan model are:

- More price transparency: farmers receive market price for their product;
- No need for intensive monitoring in the field;
- Possibility to give transitional consumptive loans during the first 2 years;
- Less financial risk for the promoter.

The disadvantages are:

- Administrative capacity to administrate loans must be created, if inexistent;
- The loan administration has cost, which reduces the yields for the farmers;

- Subsistence farmers may be resistant to loans;
- More loss for farmers in case of bad harvest.

Important factors that may influence positively the repayment rate of loans:
- Feasibility studies are based on realistic yields
- Loans are issued in kind (seeds, fertilizer)
- Repayment in kind (seeds) is accepted
- Good quality seed is provided
- Producers with experience in cash crops are selected
- Technical assistance is provided
- Regions are selected in which there are no other Jatropha bean buyers (avoids the deviation of returns)
- Farmers introduce Jatropha as an additional crop, on top of other, more traditional (cash) crops.

6.2.5 Conclusion

Factors that may influence the choice for a certain finance model is basically determined by the attitude of the farmers towards risks. This attitude can often be detected by characteristics like access to alternative income sources (the more alternative income sources the farmer has, the easier the farmer will accept risk of engaging in a new crop), the growth of the farmer's operations (subsistence farmers consider security - zero risk – as more important than income growth).

In general terms, one may expect that subsistence farmers are risk-aversive and will be inclined to model 1 (buying agreement).

More commercial farmers (small, medium or large) with several income sources and with an entrepreneurial spirit may be attracted to model 2 (joint venture). Possibly, these farmers are also willing to co-invest in the processing facility. Many of these farmers will also be using diesel generated equipment. If this is the case, farmers do not only generate an extra income but also make important savings on their fuel bill.

Model 3 (loans) seems to be an appropriate option in the expansion phase when good seeds are available, yields predictions are reliable and appropriate agricultural practices have been determined and adapted to the local context.

Obviously, within one project different financing models may be applied, depending on the characteristics of the target groups. For example, in order to assure that there is a minimum production to make a press facility viable, a mixed model may be applied in which one larger farmer works in a joint venture with the promoter (model 2) and a large number of small farmers (*out-growers*) have a buying agreement according to model 1.