## 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 30°N and 35°S. 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.

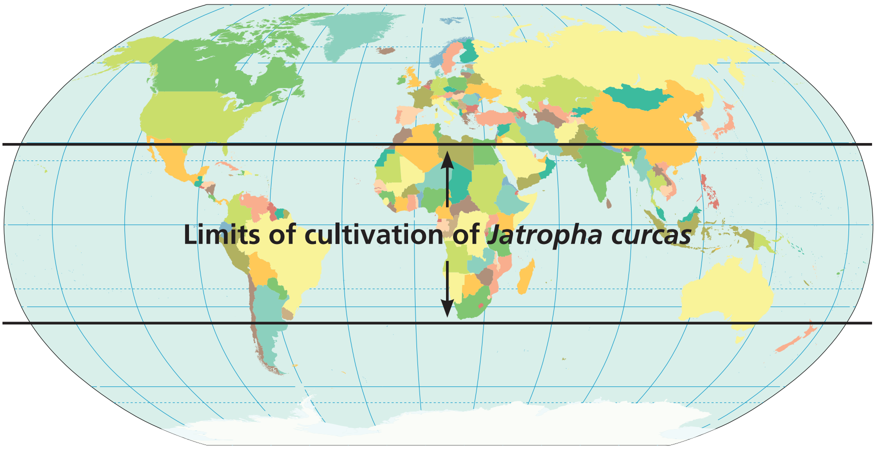


FIGURE 6: **Cultivation limits of *Jatropha curcas***

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

Photo: MESSEMAKER

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

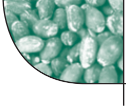


TABLE 2: **EFFECT OF FERTILIZER LEVELS ON YIELD PARAMETERS OF JATROPHA CURCAS AT ICRISAT, THREE YEARS AFTER PLANTING (INDIA)**

| | **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

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.

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.

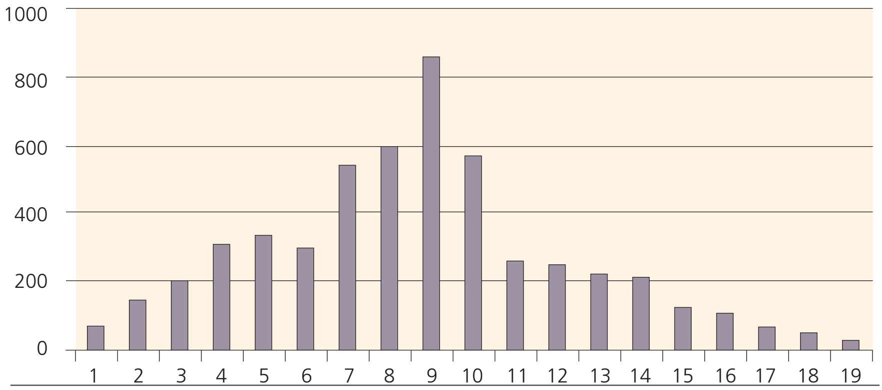


FIGURE 7: **Jatropha seed yield for 19 individuals (grams per year) averaged over four years, on poor soil and with no inputs.**

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.

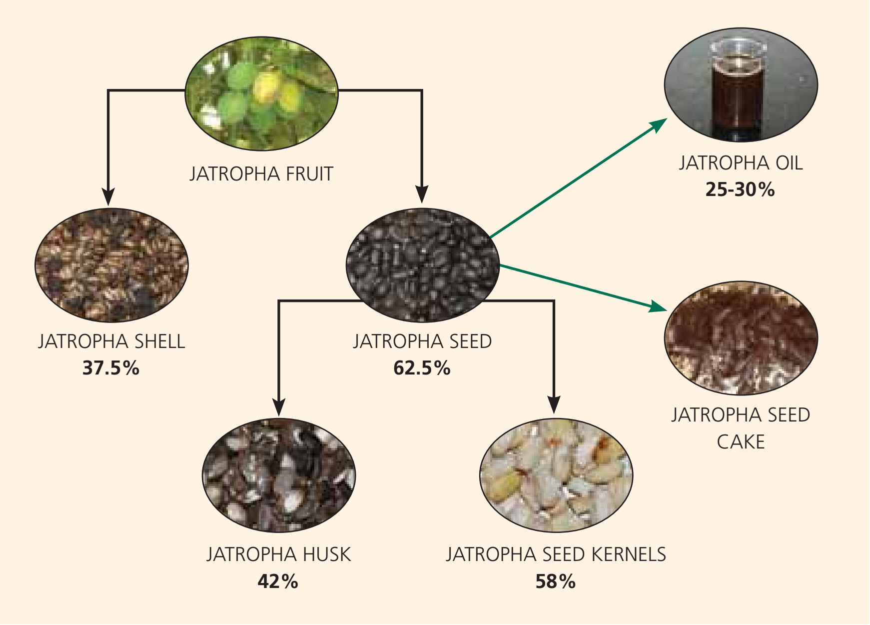


FIGURE 8: **Composition of jatropha fruit.**

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 ($S0_2$) 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:

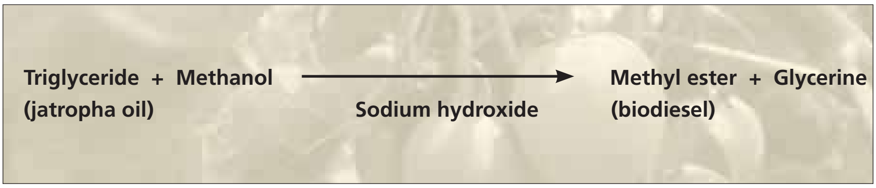
**Inputs:**

- 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.



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

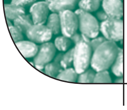
Jatropha seed cake is high in protein – 58.1 percent by weight compared to soy meal's 48 percent – and would be a valuable livestock protein feed supplement if it were not for its toxicity. Currently, removal of toxins is not commercially viable. Using non-toxic varieties from Mexico could make greater 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