Assessment of the potential of *Jatropha curcas*, (biodiesel tree,) for energy production and other uses in developing countries

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Introduction

There is a growing interest in *Jatropha curcas* as a biodiesel "miracle tree" to help alleviate the energy crisis and generate income in rural areas of developing countries. Jatropha is becoming a poster child among some proponents of renewable energy and appropriate technology, especially as an oil-bearing, "drought resistant" tree for marginal lands for small farmers. Forgotten perhaps is that a great share of the farmers in developing countries only have access through some form of limited tenure to a very small plot of land needed to grow food crops. Not to be forgotten, marginal yields are obtained from plants grown on marginal lands. To be economical as a biodiesel fuel, Jatropha must be produced in volume, and those who stand to profit the most are the processors, retailers and the "middle-men;" the latter have a history of exploiting vulnerable small producers by paying only a fraction of the actual value of their product.

There may seem to be a great amount of marginal land in developing countries that is not being used and where Jatropha could be grown; however, most often these lands are for communal use to graze/browse livestock. Jatropha is toxic to livestock, weedy, and not a good species to use in agroforestry systems except as living fences to protect food crops from livestock; and Jatropha wood is of little value for fuelwood and charcoal. Closely spaced, Jatropha would eliminate grasses and shrubs on which livestock feed; livestock that are especially important for women and children, for they are either eaten or sold to purchase nutritious food to supplement their meager diets. Also without some form of tenure recognized by the community, it is almost impossible for individual farmers to plant, protect and manage trees on these lands and benefit from their labor – thus these lands remain "the tragedy of the commons." **Haiti is a classic example of this conundrum, where these lands are under the jurisdiction of the Tax Bureau.**

There is a growing interest in *Jatropha curcas* as a biodiesel "miracle tree" to help alleviate the energy crisis and generate income in rural areas of developing countries. Jatropha is becoming a poster child among some proponents of renewable energy and appropriate technology, especially as an oil-bearing, "drought resistant" tree for marginal lands for small farmers. Forgotten perhaps is that a great share of the farmers in developing countries only have access through some form of tenure to a very limited area of land needed to grow food crops. Not to be forgotten, marginal yields are obtained from plants and trees when grown on marginal lands.

In the quest for a magical silver bullet, yet another "miracle tree", people working on developing country issues often forget that trees are no different than any other agricultural crop, and obtaining optimal yields is dependent upon a variety of things including: a) the use of improved germplasm, selected for optimal yield of nuts with an optimal amount of oil, and b) matching this germplasm to sites with fertile soils and adequate moisture that will allow it to express its genetic potential to produce optimal yields. Most often, marginal lands lack either adequate nutrients or moisture or both; that's why they are marginal, and as the old saying goes, "There is no free lunch." Trees, as do other plants, mine nutrients from the soil, and for optimal and sustained production, these nutrients must be replenished. Although *Jatropha* may look promising as a tree/shrub for marginal lands, without added nutrients, moisture and improved germplasm, marginal yields can be expected.

Well intended development efforts often fail when project subsidies are no longer there and funding runs out. The successful processing of oil nuts and the use of these oils in India is often used as an example to justify the development of oil nut projects in other countries. Often forgotten is that these enterprises are based on the processing of an adequate year-around supply of a variety of oil nuts that allows entrepreneurs to amortize the relative expensive machinery over a period of time, pay their help, and to make a decent profit. Also in India, an established traditional market for these oils already exists. Projects based on a single source of oil, such as that from Jatropha, which produces an unsure yield of nuts only during a short period of time (once or twice a year) and may not produce optimal yields for several years, may prove to be problematic and unsustainable.

To optimize oil extraction from Jatropha seeds and to produce a quality of oil that will maximize profits (e.g., a diesel oil substitute) requires: equipment, some quite expensive; chemicals, such as methanol and caustic soda, that are highly flammable, toxic and dangerous to use and are somewhat costly and not readily available; and infrastructure and trained personnel that must be in place in a timely manner. Nevertheless, it is a forgone conclusion the use of refined Jatropha oil as a substitute for diesel fuel and for soap production may have the potential to improve the livelihood of the people in rural areas by providing additional income; but only if the right conditions exist.

The jury is still out on the economics of Jatropha oil as a substitute for diesel; however, if one is to look at its potential for alleviating rural poverty, one must examine the potential of Jatropha in its entirety as part of a system. **Nevertheless, the IPGRI report quotes the comments of one astute observer, Jatropha "oil is competitive with imported diesel, especially in remote areas where fuel is often not available."**

Perhaps we may learn from Lewis Carrol who wrote in his classic *Through the Looking Glass* (Alice in Wonderland): "Cheshire-Puss," she began rather timidly "…would you tell me please, which way I ought to go from here?" "That depends a good deal on where you want to get to." said the cat.

Note: Some of the biggest advocates for Jatropha are those who are selling seeds (of unknown genetic potential), who stand to make the profits in the near term. Often, in many calculations of projected profitability, one or more of the costs of establishment, harvesting, transport, processing and marketability may not be included, while the over-valued speculation of selling carbon credits is; therefore, a somewhat distorted view of bottom-line economics is presented.

Some common names

Common names include: Jatropha, physic nut, Barbados nut, purging nut, pig nut, fig nut, and it is sometimes referred to as the biodiesel or diesel tree (not to be confused with *Copaifera langsdorfii* Desf., which grows only in moist tropical forests).

Description

Jatropha curcas L belongs to the euphorbia family and is a drought-resistant bush or small tree with spreading branches and stubby twigs that grows to 20 feet high under favorable conditions. When propagated from seed five roots are formed - one tap root and 4 lateral roots. Plants propagated from cuttings normally develop only lateral roots with one perhaps developing into a psudo-tap root that may reach only 1/2 to 2/3 the length of a normal tap root.

Jatropha has both male and female plants, which may produce different yields of nuts. Dormancy is induced by fluctuations in rainfall and temperature/light; nevertheless, not all trees respond simultaneously. In a hedge you may have branches without leaves beside ones full of green leaves. The life-span of Jatropha may be more than 50 years; however, termites are reported to attack older trees.

Toxicity

The leaves and nuts of Jatropha are toxic (containing Phorbol esters and curcin, a highly toxic protein similar to ricin in Castor), and although purgative, the nuts are sometimes roasted and dangerously eaten. However, a non-toxic variety is reported to exist in Mexico and Central America that is used for human consumption after roasting, and does not contain Phorbol esters; but, the curcin content was not mentioned. (Also see section on ***Constraints and Limitations.***)

Distribution

Jatropha is thought to be native to Central America and Mexico where it occurs naturally in the forests of coastal regions, since it is not found in these forms of vegetation in Africa and Asia, where it is found only in the cultivated form. However, Jatropha is almost pantropical now, and although toxic, it is widely planted as a medicinal plant. A non-toxic variety is reported to exist in Mexico and Central America. A species said to be endemic to Madagascar (Madagascars), J. mahafalensis, is reported to have equal energetic promise.

In many parts of Africa and elsewhere, Jatropha is widely planted as a hedge or living fence to protect field crops since the foliage is toxic to animals. **It is listed as a weed in Australia, India, Brazil, Fiji, Honduras, Panama, El Salvador, Jamaica, Puerto Rico, and other parts of the Caribbean.**

Ecology

Jatropha sheds its leaves during the dry season. The current distribution shows that introduction has been most successful in drier regions of the tropics with an average annual rainfall between 300 and 1000mm, **and occurs mainly at lower altitudes**

(0-500m). It is not sensitive to day length. It grows best on well-drained soils with good aeration but is well adapted to marginal soils with low nutrient content; although in heavy soils, root formation is reduced.

Ranging from Tropical Very Dry to Moist through Subtropical Thorn to Wet Forest Life Zones, Jatropha grows well with more than 600 mm of rainfall per year, and it withstands long drought periods. With less than 600 mm it cannot grow except in special conditions like on Cape Verde Islands, where the rainfall is only 250 mm, but the humidity of the air is very high (rain harvesting). Jatropha can withstand only a very light frost that causes it to lose all of its leaves, and the seed yield will probably sharply decline.

Propagation and Cultivation

Jatropha grows readily from seeds or cuttings; however, trees propagated by cuttings show a lower longevity and possess a lower drought and disease resistance than those propagated by seeds. Trees produced from cuttings do not produce true taproots (hence less drought tolerant), rather they produce psudo-taproots that may penetrate only 1/2 to 2/3rds the depth of the soil as taproots produced on trees grown seed. Clonal propagation by cuttings or other methods from trees that are known to produce high yields of seeds is the fastest way to develop high yielding varieties; however, this results in cytoplasmic uniformity, making high-density Jatropha plantings more susceptible to insect and disease infestation.

Spacing between plants influence yields, and those with wider spacing have the highest seed yields (e.g.; 3m X 3m), likely a result of reduced competition for moisture and nutrients. (**IPGRI**)

Plants inoculated with mycorrhizae will likely survive stressful conditions and give higher yields since this fungi increases drought tolerance of plants by facilitating the transport of moisture to and within the root system. The uptake of other nutrients essential for plant growth is also facilitated by mycorrhizae, and it has the ability to convert unavailable forms of phosphorus to forms available for plant uptake.

Vegetative propagation: Cuttings strike root so easily that Jatropha can be used to quickly establish living fences or hedges. Thicker (3 cm) and longer (30cm) cuttings develop more roots and have a higher survival rate. Treating cuttings with IBA (indole-butyric acid) hormone did not promote root formation. Rooting of stem cuttings is influenced more by: the age of the plant from which cuttings are taken; the position of the cutting within the plant; and good rooting media, aeration and drainage. Hedges planted by cuttings develop more extensive lateral root systems, and compete for moisture and nutrients if they border other crops. Jatropha would not be a good agroforestry species.

With good rainfall conditions, nursery produced plants (not clear if these were from cuttings or seed, ed.) are said to bear fruit after the first rainy season, with directly seeded plants bearing fruits for the first time after the second rainy season. With vegetative propagation, the first seed yield is higher than from plants established by direct seeding. Differences in seed fruit yields from plants produced from the different methods of propagation will probably disappear after a few years; however, when stressed from low rainfall, the direct-seeded plants will more than likely produce higher yields since more developed taproots allow plants to access moisture at lower depths.

According to the IPGRI report, plants propagated by cuttings show a lower longevity and possess a lower drought and disease resistance than plants propagated by seed.

Direct seeding: Direct seeding gives mixed results on survival, which is heavily influenced by the timing, amount of rainfall and the depth of planting. Jatropha planted by direct seeding are said to live longer than if planted by cuttings and this method is recommended for plantation establishment.

Harvesting

For medicinal purposes, the seeds are harvested as needed. The active medicinal compounds might be extracted from the seed, before or after the oil, leaving the oil cake for biomass or manure. According to the IPGRI report, the best pickers in Nicaragua harvest up to 30kg of fruits (18kg of seeds) per hour. Freitas (cited by IPGRI) reported two harvest times, corresponding to the flowering times. Observations by other authors showed that the main harvest occurs several months after the end of the rainy season, since flowering is connected to vegetative development. For energy purposes, seeds should be harvested all at once so that processing can be more efficient and profitable.

Overview of potential products and uses

In India, pounded leaves are applied near horses' eyes to repel flies. Nuts can be strung on grass and burned like candlenuts. The oil has been used for illumination, making candles and soap, adulterating olive oil, and making Turkey red oil. Mexicans grow the shrub as a host for the lac insect that secretes resin used as a dye and to make shellac. Ashes of the burned root are sometimes used as a salt substitute. Jatropha has been found to have strong molluscicidal activity and the latex to be strongly inhibitory to watermelon mosaic virus. It is also listed as a homicide, piscicide and raticide.

Jatropha is considered as a poor quality fuelwood since the soft wood burns too rapidly. In Africa, Jatropha is widely planted as a “living fence” and hedgerows to protect food crops from damage by livestock and as a windbreak to prevent soil erosion moisture depletion. In Madagascar, Jatropha is used as a support plant for Vanilla. The bark is reported to yield tannin in commercially useable quantities. In a startling 1982 study, several oil-energy species with the potential to grow in Malagasy

(Madagascar) were compared, and Oil palm was considered energetically more promising than Jatropha; nevertheless, around 10,000 ha have been planted to Jatropha (although the citation did not specify whether the plantings were *J. curcas* or *J. mahafalensis,* ed.). Other studies conclude that using the oil to make soap is more profitable than using it as biodiesel; however, this was before the recent rise in fuel costs.

Medicinals:

Although toxic, Jatropha is known as the physic or purging nut for its use as purgative/laxative, and is widely known as a source of medicinals for treatment of a variety of ailments. A range of healing properties have been ascribed to leaf preparations for both topical application and ingestion. Duke provides a most extensive list of its various uses in folk medicine.

Human consumption:

Jatropha can be toxic when consumed; however, a non-toxic variety of Jatropha is reported to exist in Mexico and Central America, said not to contain toxic Phorbol esters. This variety is used for human consumption after roasting the seeds/nuts, and "the young leaves may be safely eaten, steamed or stewed." They are favored for cooking with goat meat, said to counteract the peculiar smell. As such, it is suggested by some that “This non-toxic variety of Jatropha could be a potential source of oil for human consumption, and the seed cake can be a good protein source for humans as well as for livestock.” This non-toxic variety has not been studied as well as the toxic varieties; therefore, its properties and yields are relative unknown and “claims” unproven. The IPGRI study reports …that the seeds are edible, once the embryo has been removed (no indication of which variety, ed.).

Jatropha Oil:

It is unclear how much genetics play in the amount of oil contained in Jatropha seed and kernels; nevertheless, estimates of the oil content in seeds range from 35-40% oil and the kernels 55-60% (www.jartropha.org). However, the amount of actual oil produced from seeds and kernels is contingent upon the method of extraction, with hand presses extruding only about 20% and more sophisticated a much higher quantity. The by-product of oil extraction from the seeds and kernels is called seed cake, and when oil is extracted as a cottage industry the resulting cake is said to still contain approximately 11% oil. The more sophisticated and efficient method of extraction produces seed-cake with much lower oil content.

The clear oil expressed from the seed has been used for illumination and lubricating, and more recently has been suggested for energetic purposes as a substitute for diesel. One source reports that one ton of nuts yield an estimated 70 kg refined petroleum, 40 kg "gasoil leger" (light fuel oil), 40 kg regular fuel oil, 34 kg dry tar/pitch/rosin, 270 kg coke-like char, and 200 kg ammoniacal water, natural gas, creosote, etc.

Oil for lighting and cooking:

Jatropha nuts can be strung on grass and burned like candlenuts, and the oil to make candles. Although many researchers have described Jatropha as a potential domestic fuel for cooking and lighting, with properties similar to kerosene, it cannot be used directly in conventional kerosene stoves or lamps. High ignition temperatures and viscosity (75.7 10^{-6} m2/s) as compared to kerosene (50-55 C, and 2.2 10^{-6}m2/s respectively) mean that Jatropha oil will not burn as well, and would clog up all the tubes and nozzles in a conventional stove or lamp. Approaches to circumventing these problems are being tried. A low intensity lamp with a wick has been developed. The oil lamp requires a very short wick so that the flame is very close to the oil surface. At Hohenheim University in Germany, a group is developing a special stove to solve the problems, but neither the lamp nor the stove is readily available. So far, models require kerosene both to start the stove and to clean it just before it is turned off (www.jatropha.org). (WSU)

Biodiesel:

The market that excites the most interest is that for biodiesel. However, there are several points of view that differ considerably regarding Jatropha's suitability as a substitute for petroleum products. Right now these views yield less in actual sales than in prospects. How quickly these prospects will develop depends on the observer's point of view. Jatropha oil has long been seen as a possible substitute for fuel oil for diesel engines. This is the product where interest is highest and most research is being conducted.

Unrefined Jatropha oil can only be used in certain types of diesel engines, such as Lister-type engines; but even then they require modifications, and are high-maintenance. The Lister type engine is commonly used in developing countries to run small-scale flourmills or electric generators. These engines also have to be located in warm climates because the viscosity of Jatropha oil is too high at low temperatures. However, any diesel engine, with no modification other than the replacing of natural rubber with synthetic rubber hoses (which late model engines do not have anyway), can run on Jatropha fuel once the oil has gone through a process called trans-esterification.

According to the IPGRI publication, the trans-esterification is process is normally carried out in centralized plants since the small-scale economy of trans-esterification has not been determined. During the process, methanol, a highly flammable and toxic chemical, has to be used, and this requires explosion-proof equipment that might not be available in developing countries. The WSU study contradicts the IPGR statement by claiming that the process is simple to carry out by just mixing the oil with methanol and caustic soda and leaving it to stand; nevertheless, the chemicals are toxic and highly flammable, and the processing dangerous. Regardless, this could be dangerous. Glycerin settles to the bottom of the tank, leaving the methyl ester, or biodiesel, at the top. **This warrants further investigation in order to determine which statement is true.** Perhaps both statements are true, and the former process is for more commercial-scale operations, and the latter is an "appropriate technology" developed for small-scale, cottage-industry producers.

Biodiesel is reported to be environmentally superior to petroleum diesel, for Jatropha biodiesel emits about two-thirds less in unburned hydrocarbons and almost half as much carbon monoxide and particulate matter as conventional diesel. It contains no sulfur and so emits none. From the point of view of global warming, it is neutral in its net addition to greenhouse gasses because the carbon dioxide released in combustion was sequestered when growing the crop (this claim is questionable, since CO_2 released would soon equate the CO_2 sequestered by the plants after a relative short time, ed.). The WSU study optimistically concludes that while many vegetable oils are used to manufacture biodiesel, a given amount of land will produce much more oil from Jatropha than from the common alternatives (soybeans, cotton seed, rapeseed, sunflower, groundnuts).

The glycerin by-product of the **trans-esterification** process can be used to make a high quality soap, or it can be refined and sold at a range of prices, depending on its purity, to be used in an immense range of products, including cosmetics, toothpaste, embalming fluids, pipe joint cement, cough medicine, and tobacco (as a moistening agent).

Soap production:

The glycerin that is a by-product of biodiesel can be used to make soap, and soap can be produced from Jatropha oil itself. It will produce a soft, durable soap, and the rather simple soap making process is well adapted to household or small-scale industrial activity.

The WSU study reports that in Africa where Jatropha hedgerows are widely planted to protect crops from livestock, Jatropha oil is used mainly in the manufacture of high quality soap. Soap making takes place on a cottage industry scale and is a boon to the people concerned, offering a chance to earn an income in economic environments where there are few such opportunities. The benefits accrue to the oil pressers and soap makers as well as to the farmers who provide the seed. The fact that the seed has a value is an added encouragement to the use of Jatropha shrubs as live hedges that already yield benefits in the form of livestock control and soil erosion reduction. **However in other developing countries, other oils or tallow may be more plentiful and cheaper than Jatropha oil; therefore, planting Jatropha for oil as a raw material and creating cottage industries to make soap may not be economically feasible.**

According to the IPGI report, research carried out by the Tata Oil Mills Co., Ltd. in Bombay, India, has shown that with a mixture of 75% hydrogenated Jatropha oil, 15% refined and bleached Jatropha oil, and 10% coconut oil, a soap can be produced with lathering values equivalent to regular toilet soap. As can be seen in the table below, pressing of 12 kg of seeds yields 3 liters of oil that is then transformed into soap. The soap making technology is very simple, and is a real village technology with the only investment is a hand-operated press for $150 US (this figure seems unusually high, ed.). The soap can be made in plastic bowls or buckets, and the pieces cut with ordinary knifes.

> As the table shows, the processing of 12 kg of seeds gives 28 pieces of soap of 170 g each, which is 4,760 kg. This takes 5 hours of work (estimated). The total input is added to $3.04 US.
>
> The soap can be sold for $4.20 US, and the resulting 9 kg of presscake is well appreciated as organic fertilizer and can be sold for $0.27 US; a total revenue of $4.47 US.
>
> Reduced by the input of $3.04 US, the net profit of processing 12 kg of Jatropha seeds is $1.43 US, which is about $0.28 US per hour.
>
> Even if the estimated time for processing is doubled, the net profit is about $0.15 US per hour that is more than the average wage for workers.

Skin care and cosmetics:

The seed oil can be applied to treat eczema and skin diseases and to soothe rheumatic pain (Heller 1996). The 36% linoleic acid (C18:2) content in Jatropha kernel oil is of possible interest for skincare.

Pesticides:

The oil and aqueous extract from oil has potential as an insecticide. For instance, it has been used in the control of insect pests of cotton including cotton bollworm, and on pests of pulses, potato and corn. Methanol extracts of Jatropha seed (which contains biodegradable toxins) are being tested in Germany for control of bilharzia-carrying water snails. And the pesticidal action of the seed oil is also the subject of research of International Crops Research Institute for the Semi-Arid Tropics, (ICRISAT) in India.

Other uses:

Jatropha oil is also used to soften leather and lubricate machinery (e.g. chain saws).

Seed-cake:

Seed-cake or press-cake is a by-product of oil extraction. Jatropha seed-cake contains curcin, a highly toxic protein similar to ricin in Castor, making it unsuitable for animal feed. However, it does have potential as a fertilizer, discussed in the next section below on markets. If available in large quantities, it can also be used as a fuel for steam turbines to generate electricity. When processed as a cottage industry, the seed cake still contains approximately 11% oil, has 58-60 % crude protein (53-55 % true protein content), and the level of essential amino acids except lysine is higher than the FAO reference protein. Nevertheless, without extensive processing, the seed cake is poisonous to animals, and untreated, is only good as a source of organic fertilizer.

The production of oil from Jatropha seed inevitably results in a by-product of press-cake with a high percentage of protein -- 58 to 64%. One source suggests that it would be an excellent animal feed; however, it is toxic. Pentagon Chemicals in Zimbabwe succeeded in largely detoxifying the press-cake through a combination of heat treatment and solvent extraction, but apparently it was not an economically viable option for commercial production. There are, after all, other kinds of press-cake derived in processing other tree and plant oils that do not need detoxification. Press-cake derived from the non-toxic varieties of *J. curcas* from Mexico and Central America may not be toxic, but the literature reviewed did not show evidence of this. Non-toxic varieties are not grown in southern Africa.

According to the WSU study, trials with Jatropha seed-cake have concluded that its properties compare favorably with those of other organic fertilizers with regard to nitrogen, phosphorus and potassium. However, there are issues needing to be addressed with respect to storage, the formation of organic acids, the slow degradation of lignin (shells) and the possible need for treatment with pesticides that might result from lack of microbial degradation. The improper storage of the seed cake might also result in the production of toxic aflatoxins.

Charcoal:

In simple charcoal manufacture, 70 to 80 percent of the wood's energy is wasted and lost with yields of 30 percent in an industrial processes and 15-20 percent in a less sophisticated process in developing countries where charcoal is still one of the few simple fuel options. Jatropha wood is a very light wood and is not popular as a fuelwood source because it burns too rapidly. Four samples of *Jatropha curcas* wood were measured at USDA's Forest Products Laboratory and their densities were 0.35, 0.33, 0.37 and 0.22. **The scientist concluded that Jatropha wood would not be of much value for either firewood or charcoal**.

Some have suggested converting press cake into charcoal, but press cake is much more valuable to use as a fertilizer to ameliorate the impoverished soils in the developing countries with organic matter and nutrient contained within in order to increase crop production. However if the seed hulls were chopped and pressed, it could be used as a fuel for cottage industry use. The extraction oil from Jatropha seeds/nuts is of much higher economic value of Jatropha than converting the wood to charcoal. An exception is if a large area of land was colonized by a variety of Jatropha that had very low yields of nuts/oil and there is a desire to clear the area and replant it with a variety that produced much higher yields of nuts that contain more oil.

There has been some thought to converting Jatropha seed shells into charcoal, but one needs to first seriously study what is involved, and if would you end up with an economical product. This would be economically feasible only if you had a large source of seed shells from Jatropha plantations.

Hawaii Natural Energy Institute (HNEI) scientist Dr. Michael Antal has developed a fuel cell using charcoal as its fuel. Dr. Antal's research led to the discovery of a new Flash Carbonization™ process that quickly and efficiently produces biocarbon (i.e., charcoal) from biomass. This process involves the ignition of a flash fire at elevated pressure in a packed bed of biomass. Because of the elevated pressure, the fire quickly spreads through the bed, triggering the transformation of biomass to biocarbon. Fixed-carbon yields can attain the thermochemical equilibrium limit after reaction times of 20 to 30 minutes. Feedstocks have included woods and agricultural byproducts such as macadamia nut shells (somewhat similar to Jatroha seed shells) and corncobs. In the case of corncobs, the fixed-carbon yield attained the theoretical limit, and the reaction was complete after 20 minutes. The result is a very high-quality charcoal that has the potential to be used in high-value markets and sold as barbecue fuel, a soil amendment, a digestive health aid, for steel or metal production and to manufacture activated carbons sed to purify water.

Oil expellers

More efficient oil expellers will extract a higher percent of oil from the seeds, which in turn should produce higher profits in a Jatropha system, since oil sells for more than the residual seed-cake. More efficient expellers cost more; therefore, one must have a very large amount of seed for processing and a ready market at competitive prices for the oil to make the expellers affordable. When using inefficient expellers, the seed-cake still contains at least 10% of the oil and if the seed contains 40% oil, that means $1/4^{th}$ of the oil is wasted; a huge economic loss for any business enterprise.

In 1995 a GTZ-expert in economy analysed the economic feasibility of the Jatropha approach in Mali. Two versions of expellers were studied: 1) a hand operated ram press; and 2) a motor driven Sundhara expeller powered by two different engines 2) a cheap Indian motor (Lister) that frequently broke down, and b) a more solid German Hatz motor that required very little maintenance.

Ram-press:

The calculations for the hand operated Bielenberg press indicate that the extraction of Jatropha oil with this equipment is not financially feasible under field conditions in rural Mali.

Motor driven expeller:

The results of the financial analysis indicate that for the Lister version an internal rate of return on investment (IRR) of 49 % can be projected. For the Hatz version, the profitability of the oil mill is lower (26 % IRR) due to the more expensive equipment, but also carries a much lower risk of mechanical breakdowns.

Yields and Economics

Jatropha is being heralded as a tree crop for biodiesel production and increasing incomes of small farmers on marginal lands; however, when you plant crops on marginal lands/soils, you can expect to get marginal yields. Plants mine nutrients from the soil, and to maintain yields, these nutrients need to be replaced. This often means applying chemical fertilizers that even if available, are not affordable to many small farmers. When doing realistic planning on the "real" economics of a Jatropha project, one must also calculate that fact that optimal seed yield of Jatropha won't be obtainable for several years. Furthermore, marginal farmers most often have access to only a minimal amount to land for food crop production; therefore, what will they have to eat until a sound market for Jatropha oil is developed?

The jury is still out on the actual seed and oil yields one can count on from Jatropha plantings. IPGRI concludes that "The low yields revealed in several projects may have been caused by the fact that unadapted provenances had been used. If investigation of its genetic diversity and its yield potential had been covered by adequate scientific research, this problem could have been overcome."

In the literature reviewed, it could not be determined if adequate research on germplasm improvement is taking place to optimize the per plant yield of nuts and oil content. Since Jatropha clones are readily propagated through cuttings, germplasm improvement to optimize yields should be easier than with many other plants/trees. One must be very careful in selecting a good source of Jatropha germplasm for projects since there is little truth in advertising, and presently the best profitability is in selling seed, cuttings or seedlings produced from plants that are probably not genetically improved and may vary widely in yield. Cloning creates cytoplasmic uniformity in plants making them more susceptible to disease and insect infestation.

Both male and female Jatropha trees are reported; therefore, logically, one might assume that they might produce different yields, but yield differences were not noted.). [ECHO Editor: I suspect that what is meant is that some plants are female and others are bisexual, as is the case with many commercial papaya varieties. Otherwise it is hard to see how the male-only plant would bear fruit.] In an Australian-funded project, the Nicaraguan plant material -- a male sterile plant – was observed to have produced more fruits than the hermaphrodite types. And according to the **IPGRI** document, male sterile plants will facilitate breeding efforts for higher seed production. Also, it is probable the non-toxic varieties yield less than the toxic varieties (both in tonnage of nuts and percentage of oil

Furthermore from the literature it is extremely difficult to determine what actual per hectare yield of nuts one can rely upon when growing Jatropha. Most figures cited were projections that often are inflated and over optimistic in order to procure funding for projects. Also, the estimated oil content of the nuts cited in the literature varies considerably, which adds to the difficulty of calculating the profitability of growing Jatropha. Furthermore, optimizing oil extraction from the seeds requires expensive machinery. One can find on page 36 of the IPGRI study a list of yields cited by a number of sources.

Rather than being based on sound economic planning, many undertakings of Jatropha plantings seem to be based on subsidized project development and the speculative selling of Certified Emission Reductions for potential carbon sequestration trading payments. The cited value of carbon sequestration by Jatropha is questionable, since even if it is closely-spaced the wood is not very dense (densities 0.35 to 0.22, see above Charcoal).

In the literature, the reports of yields vary greatly and are confusing. This can be attributed to one or a combination of the following factors including: yields are sometimes given in terms of fruits, seeds, nuts, or kernels; confusing terminology used in making yield estimates, e.g., some are made in tons (t) while others are in metric tons (MT); variance in germplasm; unstipulated spacing between plants; no specific data on soils (ranging from marginal to fertile, and if fertilizer was applied); no information on rainfall and other climatic conditions, and if irrigation is being used

Reports on yields include that from plantations (mostly projected yields), but it is not mentioned if they were established by vegetative propagation or by direct seeding, on fertile or marginal soils, and if the plantations were irrigated or not. When irrigated, Jatropha trees are said to produce seeds throughout the entire year. Often, there is no mention of the age of the trees/shrubs, nor is the variety/cultivar given. Jatropha trees are said to begin producing a measurable amount of nuts at 18 months, but are not expected to reach maturity and optimal yields until after 6 years.

The IPGRI report gives a conversion factor of 30 kg of fruits yielding approximately 18 kg of seed. One might assume that the fruit to seed ratio may be higher in areas of higher rainfall. In one reference, IPGRI estimates that a yield of at least 2-3t (not MT) of seeds/ha can be achieved in semi-arid areas; however, in another citation, IPGRI reports that in Hisar, Bangalore, India, a "quite high seed yield" (1,733 kg/ha or 1.733 MT) was observed in one cultivar. IPGRI confuses the issue by reporting the yield in tons and not MT (this could have been an editing mistake, ed.), while giving the area in hectares.

Gaydou, et. al. (cited by Duke) gives a seed yield approaching 6–8 MT/ha with approximately 37% oil, and such yields could produce the equivalent of 2,100–2,800 liters fuel oil/ha. According to Gaydou, there are approximately 10,000 ha of Jatropha in Madagascar, each ha producing about 2,400 liters of oil for a total potential production of 24,000,000 liters. One reference reports that *J. mahafalensis* (not *Jatropha curcas*) as the species found in Madagascar, nevertheless, it is predicted to have equal energetic promise. Nevertheless, there has been a request from Madagascar for information on converting Jatropha wood to charcoal; therefore, one might assume that the Jatropha plantings may not be profitable and producing as much oil as predicted. A Jatropha plantation in Nicaragua is said to produce 5 metric tons per hectare. A plantation project in South Africa attached to SORSA (see later in this section) very optimistically projects a yield of 12 tons per hectare after 6 years of growth.

As a footnote, Duke adds: "The higher yields reported in my online energy book

[http://www.hort.purdue.edu/newcrop/duke_energy/dukeindex.html] are all to often for the best germplasm with the best farming techniques and in the best terrains; rarely if ever all available to the less-than-best class."

> Added 18 August 2006 -- Correspondence with Dr. K.S. Varaprasad, Officer-in-charge of India's National Bureau of Plant Genetic Resources reveals that "ICRISAT does not have any germplasm that yields 7 tons of seed per hectare. In fact, there are no systematic studies on *Jatropha*, but recently we have started work at ICRISAT; however, a few germplasm accessions have been collected by NBPGR, and those are now being characterized for their potential and other parameters."

The Washington State University (WSU) assessment states that 12 MT of nuts per ha could be expected from trees after 6 years growth; however, no data is given to support this optimism. If such yields were possible, it would only be achievable under ideal conditions, using genetically improved germplasm, fertilizer, irrigation, and other necessary inputs.

Henning reports that in an experimental plantation of Jatropha in KwaZulu-Natal, South Africa, some 18-month-old trees were already producing large amount of seeds. The trees were about 1.50 meter in height, and they were producing approximately 2.5 kg of seed per tree. A much larger project involves the construction of a refinery for biodiesel in KwaZulu-Natal, with an associated Jatropha plantation to furnish some of its supplies of seed, while other sources purchased from small farmers.

In the pilot zones in Mali the average length of hedges was found to be 15.000 m (neither the spacing between the plants nor the width of the hedgerows is given). Each meter of hedge produces 0.8 kg of seeds and an estimated 12 tons of seed can be collected from hedgerows in the average village.

Henning also reports that by promoting the integrated utilization of the Jatropha plant, the Jatropha System can provide direct financial benefits to the rural economy. To illustrate this with a rough calculation, assume the average village of the pilot area has 15 km of Jatropha hedges, which represents 12 tons of seeds.

These 12 tons of seeds may generate 2,800 US$ of cash income when the oil is extracted by an efficient expeller and the products are sold. (Labor costs to harvest the nuts and to expel the oil are not included in this calculation, nor is taken into consideration who will profit since the hedgerows are part of a village and not individually owned; e.d.). In Mali, the men own the land, thus they also own the

Jatropha hedges. As such, it is likely that little of the profit from the sale of the seed will go to the women and benefit the children.)

9,000 kg of presscake	@ 0.03/kg	= 270 US$
2,400 liters of oil	@ 0.60/l	= 1,440 US$
600 kg of sediment	@ 0.15/kg	= 90 US$
Total		1,800 US$

If we take the real example of an entrepreneur in a small village near Bamako, who buys the seeds for soap production and hires the people for the production process (extraction with Bielenberg ram press, soap production, see table above), the cash income for the village population including the entrepreneur, amounts to 3,630 US$.

If only seeds are processed and the oil and the by-products presscake and sediment are sold, a total sum of about 1.800 US$ will stay in the village. If the oil is processed by an entrepreneur to soap and the soap is sold, then the total of about 3,600 US$ will stay in the village. According to Henning, if these figures are extrapolated and used to calculate the economics of Jatropha plantations, a profit in the range of cotton farming is within reach (extrapolation is risky at best, ed.).

However, in the above calculations the price of the seeds to the processor is mainly the cost of labour to collect them (no profit to the owner). **At the time of Henning's report, if the seeds were processed as biodiesel, only under special conditions would it be competitive as a substitute for diesel in Mali or in Zambia**. Similarly at that time in Tanzania, Jatropha oil was being traded in only small quantities for 2 US$ per litre, about 3-times the price of diesel fuel at the filling station; therefore, the oil was made into soap, or sold to soap makers, and the profit used to buy diesel.

Besides genetic differences on the tonnage per hectare yield and the actual amount of oil contained in the seed, the extraction process of the oil from the seed is a major determinant of the actual amount of oil that can be obtained. To optimize oil extraction from the seed, expensive expellers must be used, and the oil has to be processed before it is usable as a fuel, and both processes increase project costs, and decrease profits.

Constraints and Limitations

Oil extraction:

A key determinant of the economics Jatropha as a source of biodiesel fuel is the efficiency with which oil is extracted from the seed. It also determines the economics of soap production. The hand-operated ram press used by many small-scale producers to extract oil yields only 20 to 30% (assuming what is meant is that the oil content of seeds ranges from 35-40%., and of that amount, only 1/2 to 3/4ths of the potential oil is extracted; ed.), and processing is very slow (pressing between 100-500kg of seed per day). Yields of up to 35% can be obtained using a diesel or electrical powered spindle press, and depending on the size of the press, up to 5 MT of seed can be processed per day. However, with the initial capital cost of a spindle press being at least 4 times higher than that of a ram press, its purchase is beyond the capability of most small-scale processors. Moreover, since diesel oil or processed Jatropha oil is needed to fuel the spindle press extrapolator, which eats up much of the profits, this makes it less attractive to such processors. Thus at the time of the reports, functioning enterprises in the industry were generally small-scale processors of oil and soap.

Oil storage:

According to Marc Portnoff, senior scientist at the Carnegie Mellon Center for Advanced Fuel Technology, Jatropha oil does not store well without processing, perhaps for only a few months; therefore, this would make it difficult to provide fuel to power the year-around operation of small industries such as grain mills, oil presses, water pumps and electricity generators (Presentation at the ***Environmental Vulnerability in Haiti: A Stakeholder Workshop to Discuss Findings and Recommendations with USAID's technical Assessment Team***, 8/02/06, Woodrow Wilson International Center for Scholars) [ed. This paragraph was added 18 August 2006]

Toxicity:

Duke reports, "The poisoning is an irritant, with acute abdominal pain and nausea about 1/2 hour following ingestion. Diarrhea and nausea continue but are not usually serious. **Depression and collapse may occur, especially in children**. Two seeds are strong purgative. **Four to five seed are said to have caused death**, but the roasted seed is said to be nearly innocuous. (It is unclear if this citation refers to the toxic variety or variety reportedly found in Central America and Mexico; ed.) Bark, fruit, leaf, root, and wood are all reported to contain HCN …. Seeds contain the dangerous toxalbumin curcin, rendering them potentially fatally toxic."

Nontoxic Mexican variety:

A non-toxic variety of Jatropha is reported to exist in Mexico and Central America. Birgit Schmook (cited by Henning) reports that the seeds in the zone around Misantla, Veracruz are very appreciated by the population as food once they have been boiled and roasted. Levingston and Zamora (cited by IPGRI) report that Jatropha seeds are edible once the embryo has been removed; nevertheless on principal, consumption of seeds should be avoided. Ochse (cited by Duke) reports, "the young leaves may be safely eaten, steamed or stewed." They are favored for cooking with goat meat, said to counteract the peculiar smell. Becker (cited by Henning) suggest that "This non-toxic variety of Jatropha could be a potential source of oil for human consumption, and the seed cake…a good protein source for humans as well as for livestock." (However, there are much better oil and protein sources available at competitive prices than that from Jatropha, ed.)

Invasiveness:

Jatropha has the potential to be weedy because of its toxic seeds that can spread rather easily and create dense stands on uncultivated lands. It is reported as a weed in many places including Australia, Brazil, Fiji, Honduras, India, Jamaica, Panama, Puerto Rico, and Salvador.

Disease and insects:

Agriculture Handbook No. 165 lists the following as affecting *Jatropha curcas*: *Clitocybe tabescens* (root rot), *Colletotrichum gloeosporioides* (leaf spot), and *Phakopsora jatrophicola* (rust). Termite infestation has also been reported in overage trees. On page 41 of the IPGRI paper there is a list of 13 additional pests and diseases observed on Jatropha by different authors.

Host for cassava viruses:

In the IPGRI paper, several scientists are quoted on stating that *Jatropha curcas* can transmit cassava superlongation disease (*Sphaceloma manihoticola/Elsinoe Brasilinesis*); and another species, *J. multifida*, is an alternate host plant for African Cassava Mosaic Virus, which is transmitted by whiteflies (*Bemisia tabaci*), and it can be assumed that this also applies to *Jatropha curcas*.

CONCLUSIONS

Industry Performance and Outlook:

WSU reports that in Africa there are two commercially interesting Jatropha products, high quality soap and biodiesel. At this point only the former is developed. Soap making takes place on a cottage industry scale and is a boon to the people concerned, offering a chance to earn an income in economic environments where there are few such opportunities. The benefits accrue to the oil pressers and soap makers as well as to the farmers who provide the seed. The fact that the seed has a value is an added encouragement to the use of Jatropha shrubs as live hedges that already yield benefits in the form of livestock control and soil erosion reduction.

There are opportunities for small-scale enterprise if loans and equipment are available. When estimating the economic benefits of Jatropha, one must also include those to rural development, especially if diesel and other fuels are either not available or priced too high for the economically disadvantaged. When processed, not only can the fuel be used for electric generators and pumps for potable water for schools or health-clinics for improved health and education and for small-scale irrigation, small motorized grain mills, but the seed-cake can be used as fertilizer to increase agricultural yields.

WSU report states that creating a small-scale Jatropha enterprise may be "…something of a 'Catch 22' situation… Processors may be unwilling to look for new customers, including export customers and expand output because they can not be assured of obtaining enough raw-material from farmers, and farmers may be reluctant to expand supplies because they cannot be assured that processors will buy it." It has happened in the past.

Household food security:

There is no data available concerning the amount of food saved by Jatropha hedges. In Mali the Malian Cotton Producing Society estimates that approximately 10 % of the crops are eaten by roaming cattle. Probably the real value is higher, because food crops are grown in gardens within or near the village, where the density of roaming animals is higher. It is assumed that the hedges also act as a wind break reducing moisture loss from winds. However, the hedges may also have a negative impact on crop yields due to lateral root development that would cause the Jatropha to compete with adjacent food crops for moisture and other nutrients. Nevertheless, there is no indication that any scientific studies have been conducted to prove or disprove any of the above.

Potential conservation benefits:

The primary conservation benefits to be derived from production of Jatropha relate to improved soil management. In Africa the tree's most widespread use at present is as a live fence. In addition to protecting crops from livestock, this use reduces wind erosion and pressure on timber resources and increases moisture retention. Nevertheless, Jatropha does mine soil nutrients. Jatropha oil projects are expected to provide income and organic fertilizer to increase crop yields, as well as being an ecologically friendly source of alternative energy to rural farmers.

Jatropha oil as diesel substitute:

In **Senegal**, EnterpriseWorks (formerly Appropriate Technology Inc.) assessed the feasibility of using Jatropha oil to power small motorized grain mills and village electric generators (use in water pumps is also feasible). They concluded that with diesel at a historically low price in 1998-99, the use of Jatropha oil as a fuel substitute was not generally economically feasible, and turned to use the oil for soap production. At that time, EnterpriseWorks found that even though diesel fuel was less expensive than Jatropha oil on commercial markets, some villagers preferred to use Jatropha oil when it reduced their cash expenditures. In **Zambia** a 1998 feasibility study concluded that Jatropha oil can be produced for less than 3.000 ZMK (1000 ZMK = $0.41 US), but this is a prohibitive price for the use of the oil as diesel substitute.

Carbon sequestration payments:

According to Henning, a 5,000 ha Jatropha plantation near Luxor, **Egypt** was initiated by a British biodiesel firm based on an important financial aspect (i.e., money) that the project expects to receive from the trade of emission certificates for CO_2 sequestration. Since no data have been made available by the project, here is Henning's estimation of the money the project might apply for: 1 ha has about 1.600 plants and each has after 7 years about 200 kg of biomass, including roots with dry matter content about 25 %. This gives a biomass of 80 tons dry matter per ha. About half that weight is carbon dioxide, i.e. 40 tons. (**Given the fact that Jatropha is a very light wood, with a density ranging from 0.33 to 0.37, this figure seems extremely high, ed**.) The trade of emission certificates pays between $3 and $4.00 US per ton of CO_2 sequestration, which is about $150 US per ha. Thus, the 5,000 ha plantation can generate an estimated $750,000 US additional income due to carbon sequestration payments. [ECHO Editor: I do not see any value in reducing atmospheric carbon dioxide on any meaningful timeframe unless the sequestered carbon remained sequestered for decades or centuries.]

Henning states that it is not clear why the government of Egypt and private firms are so interested in producing biodiesel with Jatropha oil, for he had not seen any economic calculations showing that the biodiesel produced from Jatropha oil might be cheaper than the diesel fuel. Perhaps it is speculation on the trading of carbon credits and payments for carbon sequestration, and preparation for a sharp increase in fossil fuel prices. Thus, they want to get the technology ready to produce renewable fuel, and with the continuing rise in fuel prices, this seems economically viable.

Henning also reports that "In Ghana, biodiesel is won by esterification of the oil with ethanol. Ethanol – unlike methanol which is a petroleum product and would have to be imported – can be won from local agricultural products as sugar cane. The centralized nation-wide marketing of the biodiesel is done by the Ministry of Energy. This appears to make sense for Ghana, because the petroleum importation is governmental, too. However, the project operators maintain the right to market an unlimited quantity of

biodiesel on their own."

"Glycerin, the by-product of the esterification process, is to be purified and can then be sold on an extensive market. During the first stage, the demand in Ghana will be sufficient to buy the entire production. The market price is $500-600 US/ton. The presscake is modified and sold as biological fertilizer, also primarily on the local market; but import agents from neighbouring countries in West Africa, such as Nigeria, have already confirmed their interest to be supplied." "Oil-presses: stamping presses operating with 70-100 tons of pressure are needed for the cold-pressing of the Jatropha nuts. Minimum capacity: 50 tons of nuts/day, equivalent of the expected harvested quantity of ca. 1000 tons/month during 2003/2004."

India's biodiesel production model:

India private sector has a long history of exploiting oilseeds and has developed the infrastructure necessary to profit from this industry. Costly machinery, such as expellers, is amortized rather quickly since the industry isn't based on any one oil seed crop, rather its based on a number of different oil seeds that are processed year around, and the machinery is run constantly. Furthermore, the government now provides a guaranteed market and price since it has dictated that fuels must contain 10% biodiesel oil. Therefore, supply and demand for biodiesel in India is much different than in other countries with projects that attempt to create entirely new production systems.

Commemts from the field

added to ECHO Website August 18, 2006

Madagascar: Mark_Freudenberger@dai.com

Dear Mike:

I was delighted to read your perceptive paper on jatropha and I took the liberty as well of sending it around to various colleagues and to Reinhard Henning, the coordinator of the jatropha systems website. He has made some small comments and clarifications. I will send you his comments because these points are well taken and they add to factual clarity.

The ERI program in Fianarantsoa, Madagascar has been working on the question of propagation and uses of *Jatropha curcas* over the past two years. We have been carefully moving forward in doing test plantings, trying out different extraction techniques, and exploring the economic and social questions you bring up. A couple of interesting issues are coming up:

-- Presence of *Jatropha curcas:* The plant is widespread in Madagascar, but not apparently as an invasive. It is very much used as a pole plant for vanilla, pepper, and other climbing plants in many tropical areas of the country. An indigenous species, *Jatropha malfensis*, grows in the arid parts of the country. Villagers like *Jatropha curcas* because it allows these climbing plants to grow well but also be protected from heavy winds generated by cyclones. The jatropha bends over but then rights itself very easily. It does not grow too high and thus does not require much trimming. I've been surprised to see farmers in Fianarantsoa grow local varieties of ignames around jatropha plants. This reduces the labor costs of cutting branches for poles. Jatropha does not seem to be invasive because it does not tolerate well bush fires. This limits invasiveness but also makes large plantations of jatropha a risky business!

-- Oil from Jatropha: The local market for jatropha oil is quite interesting. The oil is extracted using very energy and labor-intensive techniques (boiling the seeds and skimming off the oil) and then sold in the local markets as an oil used in traditional shampoos. Women are the primary processors of the oil. Malagasy women highly value the oil for their hair as it apparently has some medicinal qualities. The price for oil is about $1.50 a litre - about three times higher than what commercial firms like D-1 are currently offering. Villagers also express keen interest in jatropha oil and the seeds as lighting and thus a substitute for kerosene. As the price for kerosene increases dramatically, villagers are increasingly turning to local oils and wood for indoor lighting. We have found that villagers are deeply interested in the simple techniques of burning jatropha oil in small lamps. They also note that the smell of jatropha oil is nicer than kerosene. It should also be recollected that in large parts of Madagascar, kerosene is not available for sale in local markets because of the poor transportation system. In times of particularly deep scarcity, villagers will even burn the seeds of jatropha attached to skewers. This works like a candle. Pure jatropha oil can also be consumed directly in the Lister or other Chinese and Indian motors. This negates the necessity of being involved in the esterification process. I agree that German motors are more efficient and durable than the Chinese or Indian motors, but local manufacturers and artisans are very skilled at repairing these Third World engines. These are the engines on the market, not the more expensive, but more efficient, European models.

-- Seedcake: As in many parts of the world, we are finding that farmers are probably more interested in the jatropha seed cake then they are the oil. The seedcake is widely known as a very valuable form of fertilizer equivalent in fertility to chicken manure. Farmers involved in traditional oil processing carefully guard the seed cake and use it to fertilize rice fields as well as up-land crops. Recently, I met with farmers who are also using the seed cake to fertilize coffee plants. They did comparison trials and found jatropha to be extremely interesting compared to more traditional forms like mulching or use of cow manure. I agree that it is crazy to use jatropha seedcake for charcoal unless the seedcake begins to be a pollution hazard. Right now, we envisage LOCAL level and small-scale processing so that the seedcake remains in the local environment and thus can be returned to the soil in the immediate vicinity of production.

-- Oil Extraction: The major problem with jatropha is the difficulty of extracting the oil from the seeds. We are testing the Bielenberg press here in Fianarantsoa. I am very well aware of the critique that it is not economically profitable. We copied the press from a model made in Tanzania using local manufacturers. They have to our surprise made very high quality presses. But, we tried other hand press models and they don't work very well. Our conclusion so far is that the Bielenberg hand press is the only thing out there that extracts oil by hand, that it can be made by local artisans, and that it appears to be far more productive than the traditional oil extraction techniques. This later point is important because the costs of firewood are very high for boiling the jatropha seed using the traditional techniques. We are putting in place a system for farmer's associations to rent out the presses so that local groups can make oil for soap and lighting. We agree that mechanized presses are by far more economically profitable, but so far these machines are expensive, difficult to obtain, and break down as well. We're testing some Chinese models and we hope that D-1 will introduce some higher quality German models. Right now, availability is severely constrained because of lack of supply, lack of credit, and skepticism.

-- Land Tenure: Your points are very well taken. As one who has worked on land tenure issues for years, this is one of our major concerns. I think the verdict is indeed out about whether farmers in Madagascar will plant massively jatropha. If the price of the seed and oil is high enough, I think they will plant and indeed resolve bit by bit the tenure insecurities. This has happened with many cash crops in the past. I don't think it will be very easy for industrial scale plantations to be launched in Madagascar because of competing uses of land for pastoralism and also because of the xenophobic nature of Malagasy landowners. They will not take to international interests buying up vast swaths of land for jatropha. If jatropha expands, it will be due to the massive planting by small farmers in various tenure niches. Our project is trying to start up a series of tenure case studies on jatropha to look at exactly the questions you raise. I do agree that jatropha in one form or another will contribute to various tenure issues. But, this happens with any new crop that generates economic value. Equity, gender, and tenure issues always crop up.

-- Agroforestry combinations: Your points are very well taken. We are very interested in the possibilities of intercropping jatropha on highly degraded hillsides with various grasses and legumes. Under wide spacing conditions, we are interested in improving hillsides for grazing (either free or cut and carry) plus also producing jatropha seeds for local, regional, and possibly international markets. I read with great interest your concern that jatropha might compete with grazing lands. Yes, its a very valid point. But, in the areas where livestock raising is in decline (ie: vast parts of eastern tropical Madagascar) and hillsides are highly degraded in a fire climax situation, we are exploring whether jatropha agroforestry combinations are a way to encourage pasture improvement, reduction in fire, but also progressive recapitalization of the livestock system. What kinds of grasses or legumes could be grown with jatropha that won't compete with the plant? We've hired a Malagasy agronomist who will look at this question and we're testing out several different cropping patterns with farmers now. The major concern is fire. Fire is a weapon, a management tool, and a major worry. If monocultures or grass-jatropha systems are encouraged, this makes the landscape possibly very liable to fire. Farmers might invest in planting jatropha but find that just at the moment of starting the harvest process, jealous neighbors could burn down the plantation! For this reason, we are more interested in jatropha uses in firebreaks, hedges, boundary markers, intercropping of jatropha with vanilla and other vine crops. etc.

-- Energy Flows and Jatropha: Good point that jatropha yields will be dependent upon the input of fertilizers, either organic or inorganic. I don't yet know how to respond to this issue. Our major inquiry is what does one do with the highly degraded *tanety* fire climax lands that are hardly used for pastoralism and that possess relatively small value. If market conditions are right, farmers would probably invest more labor in manuring, mulching, and possibly adding inorganic fertilizers to jatropha. I hope not the latter! But, from an ethical perspective, I do hope that agroforestry combinations can be devised so that jatropha is one complementary contribution to landscape restoration. Its very clear that no improved varieties of jatropha exist at this time. We don't even know what the yields per tree are at this time. For this reason, ERI is trying to start up an applied research process to learn more about yield dynamics in different growing conditions. Not an easy topic.

-- Market Orientations: ERI is promoting the expansion of jatropha with caution. We do not encourage farmers to produce soley for the international market, but rather to develop niche local markets in the immediate future for the oil and seedcake . As international market dynamics and structures develop, jatropha from Madagscar might be well positioned. We just don't yet know. We think that there is much future in the village level soap market because locally made soap, at a cheaper price and with greater availability than industrial manufactured soaps, could resolve a huge health problem. Soap availability for hand washing is very limited in villages because of high cost. Oil for lighting and simple diesel motors is also promising. Again, expansion into these markets hinges upon the availability of locally manufactured hand and mechanized presses. We suspect that the national and international market will emerge, but probably, Madagascar cannot compete with India, South Africa, or other countries where industrial scale plantations are being planted right now. But, the verdict is not yet in. If fair prices are offered to Malagasy farmers for oil processed locally, I think that jatropha production could take off. I agree fully with you that value added must occur at the local level among villagers, local level middlemen, and local cooperatives and associations. Its very risky to focus on capturing a share of the international market. It is too volatile, too many middlemen are in the business, and market dynamics are not clear. However, IF international prices remain high for biofuels due to Kyoto agreements, European Union price subsidies on biofuels, and other incentives, the international market might become interesting for Malagasy farmers and exporters. Its too early to tell.

So, these are some thoughts that jumped out from reading your excellent paper. I thank you for taking the time to write it and I hope that my comments based upon our unfolding experiences are useful.

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From: Trent Bunderson
Sent: Friday, April 28, 2006
Subject: Comments on Jatropha curcas

I was happy to see John Pratt's comments on Jatropha based on our experiences under MAFE. Mike Benge's concerns are justified. I would add that over the past 2 years, I have been contacted by a number of private sector firms (most from S Africa, but also in Malawi) to mobilize Jatropha planting efforts, either on private plantations or with communities. In all cases, I have asked questions regarding the relative benefits/returns to communities and farmers involved vs. the companies that produce and sell the oil or fuel. Some of these questions include:

-- yields and prices for the seed produced under Malawi smallholder conditions(yields usually quoted at 10 tons/ha or more, which is hard for me to accept; and prices of US$50 per ton, which is believable because it is very low);

-- relative returns to the farmer vs. other crops grown for the costs involved;

-- returns to the private companies for oil/fuel produced;

-- who benefits from carbon credits documented and how is this done and shared;

-- negative effects on the farm family system and the village environment;

-- long-term commitments by the companies that purchase and process the seed so that they don't simply disappear soon after the trees start bearing fruit - In my opinion, some of the companies involved are not exactly scrupulous.

I have never received satisfactory answers to these questions. Until this happens in a clear and transparent form, we will not promote Jatropha as a wonder tree. I know there are big plans to plant Jatropha in huge plantations in Mozambique and Tanzania, I know of 2 separate ones, each of 11,000 ha. In the meantime, we will watch and see how things develop, and who actually benefits. Best regards, Trent Bunderson

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Malawi: **From:** John Pratt
Sent: Friday, April 28, 2006 9:28 AM
Subject: Re: Jatropha curcas biodiesel miracle

Dear Autman

Thanks for this assessment. It's good to see WSU/Peter Wyeth investigations being quoted.

I agree with Mike Benge's skepticism.

There are some investors in companies making money out of playing up this scheme but it's time they laid out for scrutiny their detailed business plans and financial feasibility assessments for the whole process from planting to blending into vehicle fuel. It's fine to find an economic use for a by-product of existing Jatropha hedgerows/living fences (or wild trees) but, as Mike points out, quite wrong to promote plantations whose viability would depend on a single processor without all the numbers being laid on the table - and then the numbers would need to be very good, alongside a gaze into the crystal ball of long-term energy prices.

Jatropha plantations promotion could, as he infers, make farmers poorer rather than richer. We concluded so at MAFE in 2002 - but then oil prices were a fraction of what they are today.

Philippines: Pat Dugan

(excerpt) “In collaboration with several of our government agencies here, Fred Po has conducted studies on production of bio-diesel fuel from different sources including Jatropha. Prior to the recent oil price increase, his calculations indicated that bio-diesel from Jatropha might not be competitive at the pump with regular diesel, but could be competitive at the village level if the fuel is used in-situ to power Lister-type engines. Fred also said the Jatropha can be processed at the village level using relatively simple technology.”

Zimbabwe

Mike: We have been investigating the possibility of growing Jatropha in Zimbabwe, with great difficulty so far. I am in total agreement with most of what you say. If this crop is going to be grown to benefit anybody it has to be done on a viable commercial basis with the best possible inputs.

The Zimbabwean government’s stance at the moment is that the crop must be grown in marginal areas. Thus you break your back to plant and look after the stuff for 4 years with very little return. The poorer subsistence farmers can hardly feed themselves, now they are being told that if they plant these trees they will become rich, however it takes 4 years to see any income. No way they are going to plant it. Many of the marginal areas in Africa are natural forests or grasslands. The government is saying lets change these natural areas to Jatropha plantations. No way I am going to do that when there is fertile land in decent rainfall areas available. The government states that this land (non-marginal) must only be available for food production.

We have also found it difficult to find good information on the available seed and varieties. We do not want to go ahead and plant trees that will be outdated in 2-3 years.

We have done our own costings as per current costs in the country and we predict that you will not get away with anything under US$1500-2000 per hectare prior to production in season 3-4. Thus you only see benefit in around season 6-7 on your investment. It does look good after this though. This is a problem as the banks will not finance you for more than 18 months and there is a land tenure issue.

I am also finding it difficult to get exact information on yields dependant on agricultural practises used.

All this said and done I have no doubt that globally we need to secure our energy future and growing Jatropha for end use as diesel is one way. The region imports all its fuel requirements thus making it more viable than in countries that produce their own crude oil. It will allow smaller commercial companies to produce fuel to compete with the oil companies.

Stuart Hall

Haiti

Email exchange between the author and Marc Portnoff, Senior Scientist at the Carnegie Mellon Center for Advanced Fuel Technology, who is promoting a Jatropha project in Haiti.

All, Mike raises a valid point about how does one interpret the "body of knowledge" that is in the literature. The papers on oil properties and uses seem to be based on good science.

As I am not an agriculturist, Mike may be correct that the papers concerning yields are not hard science but anecdotal. Maybe Gael could offer comment on this point.

It is clear, that most of the scientific work being done in India, China, and Indonesia are more targeted to plantations where water and other Ag inputs are planned. In most of these cases, the scientific studies have not been completed. For example, the Indonesian Institute of Agriculture at Bogor (working with Japanese scientists) has only been working with Jatropha since 2003. They report actual yields of 4 kg/plant/year and are forecasting 7-8 kg/plant/year. These however are e-mail correspondences. I have no peer review scientific papers to confirm these numbers.

Marc Portnoff
Senior Scientist
Carnegie Mellon Center for Advanced Fuel Technology

Note:

Most of the information used in this document was drawn from a limited number of documents found on the internet and are cited below. There is a plethora of papers written on Jatropha (**some selling "snake oil"),** and the most extensive bibliography as well as research contacts can be found in the IPGRI study. Some of the studies are dated; therefore, there may be more up to date accurate data on yields and economics based on more recent calculations of the cost of diesel fuel. Specific sources of information are not cited in this paper, but they can be found by reading the following documents.

Literature consulted

Much of the information for this assessment was derived from the following sources:

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USDA. Personal correspondence with Mike Wiemann. USDA Forest Service's Forest Products Lab. Madison, WI.