PLANT RESEARCH INTERNATIONAL
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Global *Jatropha curcas* evaluation, breeding and propagation programme

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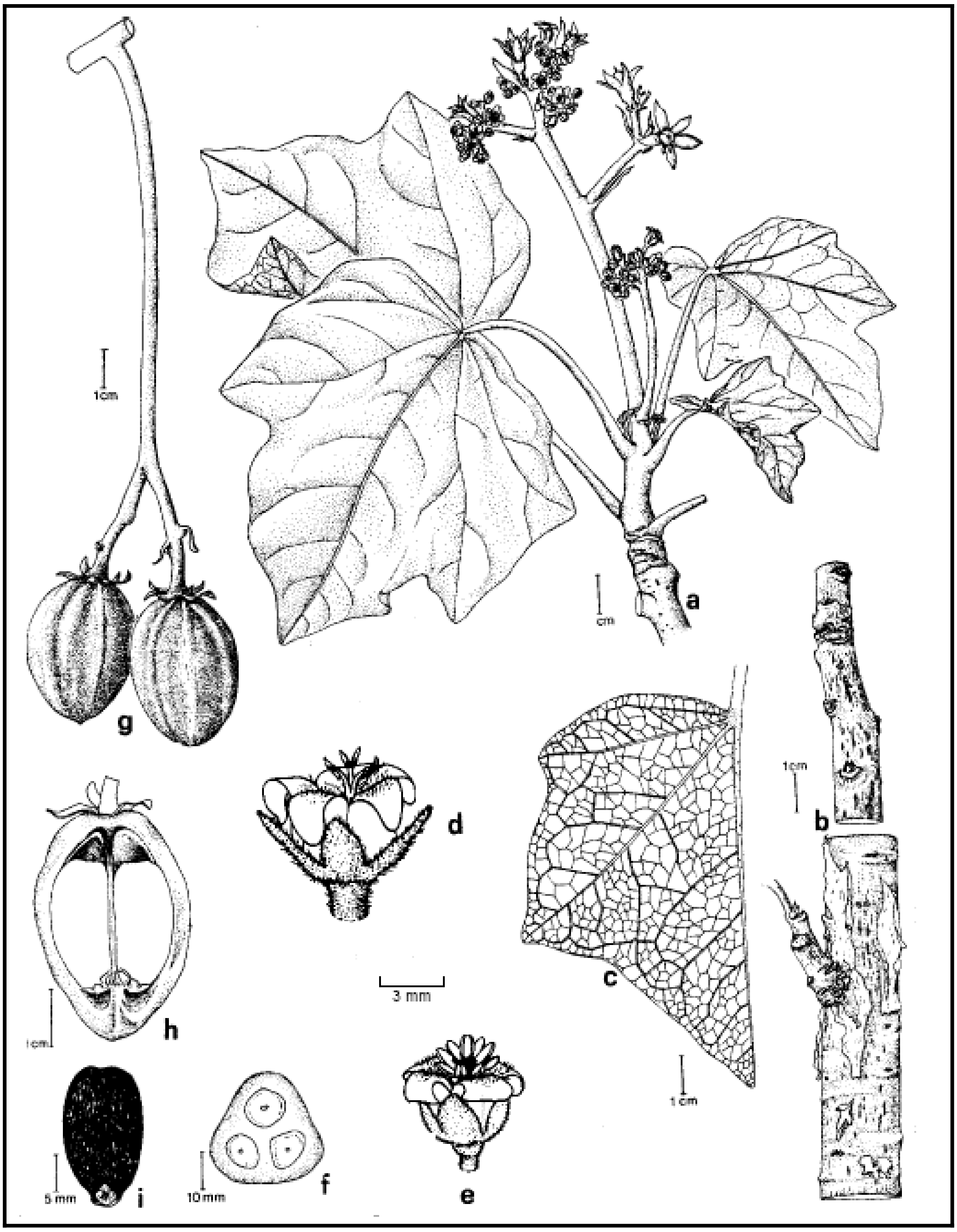

Figure 1. *Different components of the physic nut (*Jatropha curcas *L.): a - flowering branch, b - bark, c - leaf veins, d – pistillate (male) flower, e - staminate (female) flower, f - cross-cut of immature fruit, g - fruits, h - longitudinal cut of fruits; (Sources: a-c and f-h: Aponte Hernández, 1978; d-e: Dehgan, 1984; Heller, 1996).*

1. The crop species *Jatropha curcas* L.

Jatropha curcas L. or physic nut is a drought resistant large shrub or small tree, belonging to the genus *Euphorbiaceae*, producing oil containing seeds (Figure 1). The species has its natural distribution area in the Northeastern part of South America. Thus far, we have not found any particular data on ecosystems in which it naturally occurs. We think that studying the ecosystem of its natural occurrence is important, as the areas to which the plant has been distributed by men – secondary centres of diversity – are not necessarily alike, nor are the current cultivation areas. We continue to search for those data.

J. curcas is native in tropical America, but is now found abundantly in many tropical and sub-tropical regions throughout Africa and Asia (Figure 2). From the Caribbean, where the species was already used by the Mayas (Schmook & Serralta-Peraza, 1997), *J. curcas* was most likely distributed by Portuguese ships via the Cape Verde Islands and Guinea Bissau to other countries in Africa and Asia (Heller, 1996).

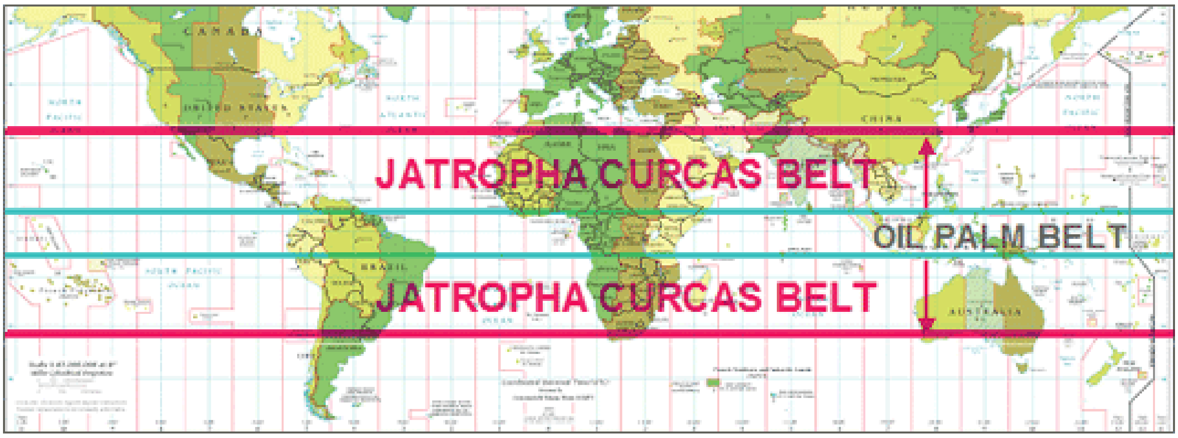

*Figure 2. Global indication of the most suitable climate conditions for the growth of Jatropha (*J. curcas *L.) (30° N, 35° S) and Oil palm (*Elaeis guineensis *Jacq.) (4° N, 8° S).*

Note that Figure 2 only provides a rough indication for *J. curcas* growth between most northern and most southern latitude, and that for instance all areas with severe or prolonged frost periods are not suitable for *J. curcas* growth.

In Figure 3 a special herbarium sheet of *Jatropha curcas* is presented. The significance of this herbarium sheet is that it is one of the original dried specimens on which Linnaeus has based the species description of *Jatropha curcas*. One of them ought to be elected as the *type* of the species thus warranting that the name is linked to a real plant species. As the original author – in this case – has not explicitly indicated a type specimen – this has been done afterwards by Radcliffe-Smith in Fl. Pakistan, Euphorbiaceae 172: 81, 1986. Therefore the herbarium sheet in Figure 3 is a lectotype of *J. curcas*.

Figure 3. *Herbarium sheet of the lectotype of* Jatropha curcas *L.*

Due to the toxicity of its leaves, *J. curcas* is not browsed and therefore traditionally used in protecting hedges around arable land and housing. Also due to its toxicity, *J. curcas* oil is not edible and is traditionally used for manufacturing soap and medicinal applications. Its oil further is only suitable for industrial processing or as an energy source (See Figure 4 and Figure 5 for exploitation and processing of *J. curcas*).

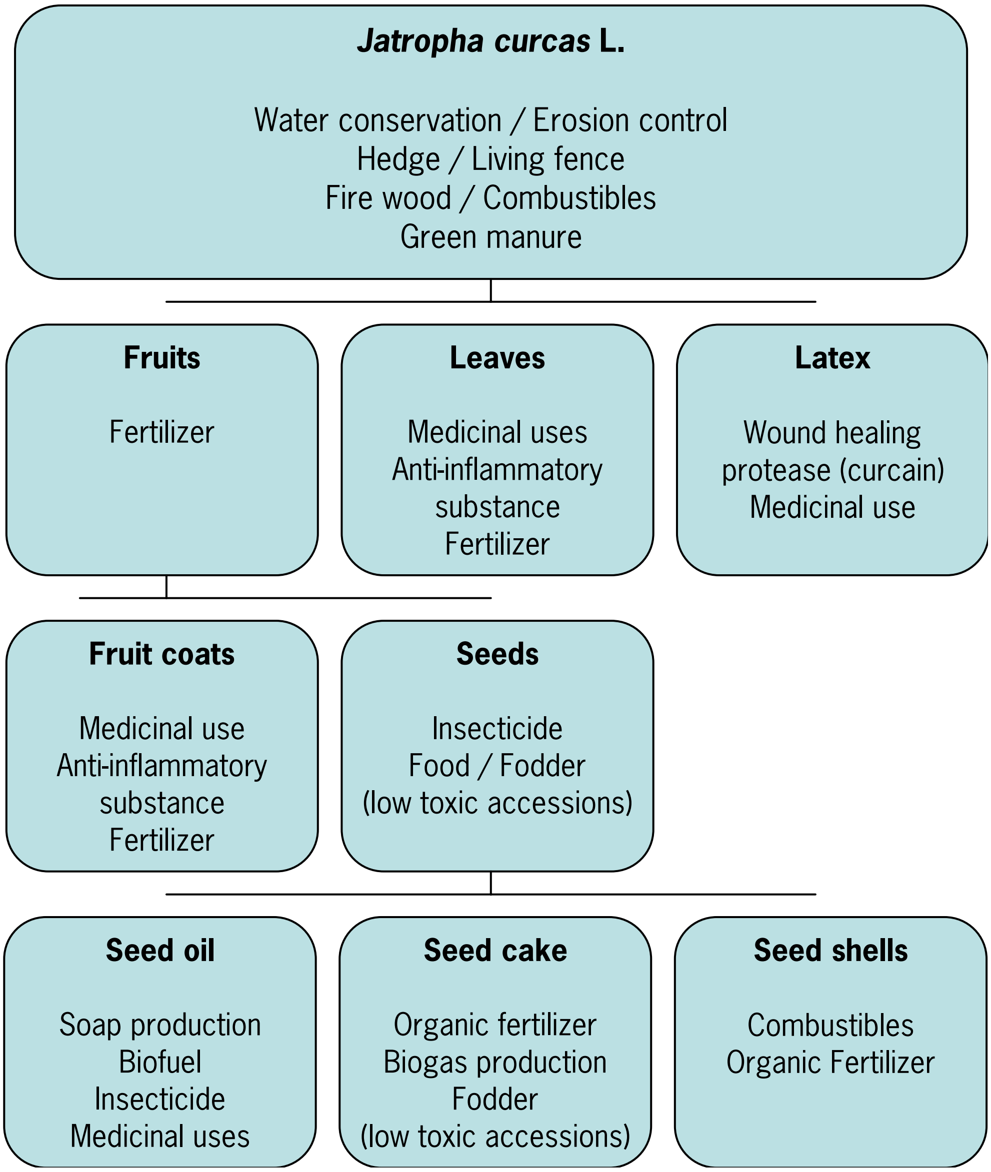

Figure 4. *Exploitation of* J. curcas *components (adapted from Gübitz et al., 1997).*

Burnt directly or after processing to, for example biodiesel, it could make an important contribution to the energy supply of emerging economies in general and remote rural areas in particular. Both are threatened in their development by scarcity and therefore increasing energy costs and could benefit from locally produced bioenergy. Furthermore, when properly managed, handled and processed, the production of bioenergy contributes to a decrease in greenhouse gas accumulation in the atmosphere.

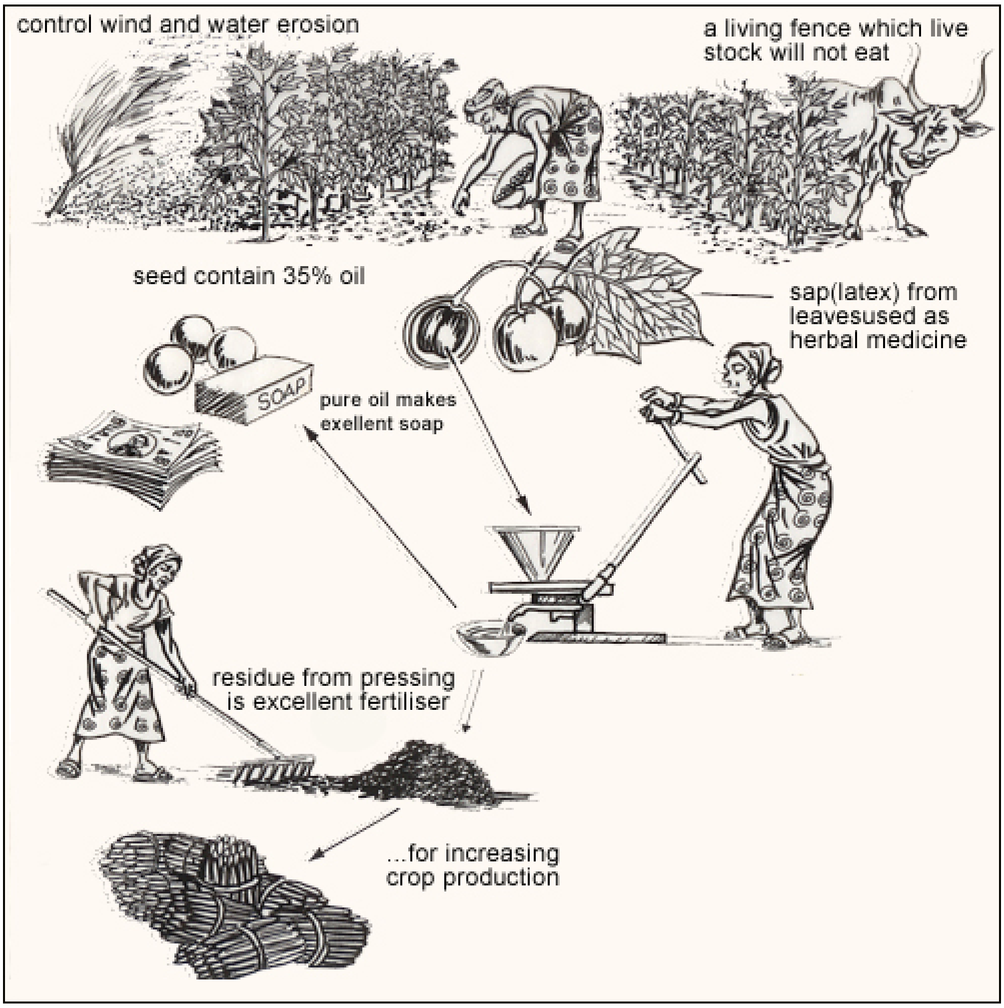

Figure 5. *Traditional use and local processing of physic nut (*Jatropha curcas *L.).*

J. curcas' potential for producing energy from marginal land without large inputs has recently created a hype of attention, resulting in the planning of huge areas of plantation in Asia, Africa and America. Predictions of productivity, however, seem to ignore the results of plantations from the 1990s, most of which are abandoned now for reasons of lower productivity and/or higher labour costs than expected (Foidl *et al.*, 1996).

Hence, a major constraint for the extended use of *J. curcas* seems to be the lack of knowledge on its potential yield under sub-optimal and marginal conditions. This makes it difficult to predict yields from future plantations under sub-optimal growth conditions, the conditions where *J. curcas* is especially supposed to prove its value. Moreover, reliable predictions of the productivity are necessary to make responsible decisions on investments.

This report aims to evaluate the expectations of productivity of *J. curcas* as an oil crop under different conditions by reviewing literature, integrated with the findings of the FACT expert seminar '*Jatropha curcas* L. Agronomy and Genetics', held in Wageningen from 26-28 March 2007 (Daey Ouwens *et al.*, 2007).

2. Claims on *Jatropha curcas* L.

It has become clear that the positive claims on *J. curcas* are numerous, but that only few of them can be scientifically sustained (Daey Ouwens *et al.*, 2007). The claims hat have led to the popularity of the crop, are based on the incorrect combination of positive characteristics, which are not necessarily present in all *J. curcas* accessions, and have certainly not been proven beyond doubt in combination with its oil production. Hard figures and verifiable data on various aspects of *J. curcas* remain scarce, and here, the latest and most important scientifically sound information is included.

The **claims projected on *J. curcas*** include that the crop:

a) reclaims marginal soils,
b) grows well under saline conditions,
c) is drought tolerant and may have low water use (or high water use efficiency),
d) has low nutrient requirements,
e) is an energy crop,
f) grows seeds with high oil contents,
g) provides high oil yields,
h) provides oil of high quality,
i) requires low labour inputs,
j) does not compete with food production, and
k) is tolerant or resistant to pests and diseases

All separate claims, facts and perspectives stated above, that have led to the hype around *J. curcas* are presented in the following sections.

2.1 Growth in marginal soils and waste land reclamation

In its natural distribution area, *J. curcas* grows in semi-arid and arid conditions (Jones & Miller, 1992; Makkar *et al.*, 1997; Openshaw, 2000) and in tropical humid areas, like in Guatemala (>4,000 mm y^{-1}) and the northern parts of Vietnam and in Thailand.
Under semi-arid conditions, *J. curcas* has a possibility for reclaiming marginal soils by exploring the soil with an adequate root system. This results in recycling nutrients from deeper soil layers, providing shadow to the soil and thereby reducing risks of erosion and desertification. Concepts for the reclamation of marginal soils are reported (Spaan *et al.*, 2004), although its oil production is not proven to be at commercially subsistent level (Francis *et al.*, 2005). It was demonstrated that soil structure increased significantly after *J. curcas* was grown for 18 months under semi-arid conditions in India; macro-aggregate stability increased by 6-30%, whereas soil bulk density was reduced by 20% (Chaudharry *et al.*, 2007; Ogunwole *et al.*, 2007). From 1999-2003, *J. curcas* could grow well under semi-arid conditions in India at precipitation rate of 246, 145, 714, 226 and 518 mm y^{-1} respectively over those years, and with supplemental saline furrow irrigation treatments in the dry period from October-June (Treatment 1: ECiw 9 dS m^{-1}; Treatment 3: ECiw 28 dS m^{-1}; Treatment 2: alternate Treatment 1 and Treatment 3). Although a growth period of 5 years is described, no production data were reported (Dagar *et al.*, 2006).

Rooting patterns are significantly influenced by propagation method. Plants originating from seeds and directly sown into the soil normally develop a rooting system with a thick primary tap root and 4 lateral roots, and with abundant and straight secondary roots (Heller, 1996; Soares Severino *et al.*, 2007b), whereas plants propagated by cuttings only develop secondary roots. Growth containers in nurseries may hamper the initial growth of *J. curcas* seedlings if container volume is insufficient. This is caused by reduced space for root expansion and not by lower availability of nutrients in the substrate (de Lourdes Silva de Lima *et al.*, 2007).

Seed size (small, medium, large) significantly [LSD 0.05] influenced various variables of seedlings 90 days after emergence: seedling height (35.80, 42.74, 46.77, [3.39]; cm); rooting depth (12.80, 14.80, 17.60, [1.95]; cm); stem diameter (9.60, 10.80, 11.05, [1.1]; mm); number of leaves (16, 17, 20, [2.3]; #) and dry matter of green biomass (1.5, 1.8, 2.1, [0.23]; g seedling^{-1}) (Mattana Saturnino *et al.*, 2005).

2.1.1 Waste land?

It should be noted that the definition of 'waste land' is rather ambiguous, and should not be confused with the term 'marginal soils' or 'marginal lands'. The term 'waste land' is sometimes used to indicate unoccupied areas (or areas where land ownership is not clear), whereas 'marginal soils' or 'marginal lands' are used to indicate areas with unsuitable conditions for crop production due to soil and climate constraints. Some experiences with *J. curcas* on marginal lands are well documented (e.g. Chaudharry *et al.*, 2007; Ogunwole *et al.*, 2007; Patolia *et al.*, 2007a; Patolia *et al.*, 2007b; Shekhawat *et al.*, 2007) and show that *J. curcas* can be well established on marginal soils and can reach reasonable production, if proper care is given to boost plant growth in the initial grow phases and maintain production by additional inputs.

2.2 Low water use

Although *J. curcas* grows in semi-arid and arid tropical areas and can therefore be considered as a drought tolerant species, there is little known on water use and water use efficiency of *J. curcas* as a crop. For the species *Jatropha pandurifolia* L. and *Jatropha gossypifolia* L. (Li Guo, 2002), a water use efficiency of 3.68 and 2.52 mmol CO_2 mmol^{-1} H_2O was reported. This value is in the range with other oil seed species like soybean (3.90 mmol CO_2 mmol^{-1} H_2O) and oil palm (3.95-4.42 mmol CO_2 mmol^{-1} H_2O).

The organic structure of *J. curcas* oil is depicted in Figure 6. To produce a mol of *J. curcas* oil, 57 mol of CO_2 are needed in the photosynthesis process: $12\ H_2O + 6\ CO_2 + \text{light} \rightarrow C_6H_{12}O6 + 6\ O_2 + 6\ H_2O$.

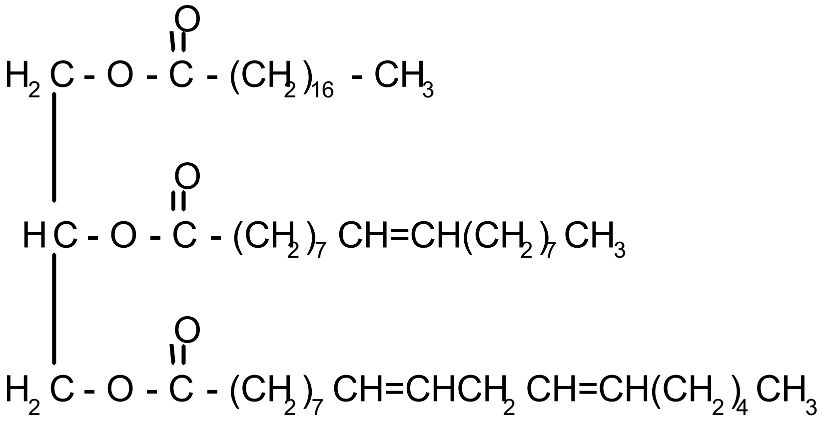

Figure 6. Organic structure of J. curcas *oil.*

For the photochemical production process, *J. curcas* oil needs 57 C (≈12 g mol^{-1}), 107 H (≈1 g mol^{-1}) and 6 O (≈16 g mol^{-1}). A mmol of *J. curcas* oil therefore weighs about 0.888 g. At a water use efficiency of about 3 mmol CO_2 per mmol H_2O, about 57/3 = 19 mmol H_2O (or 0.342 g H_2O) is needed to produce 0.888 g of oil. This is equivalent to 0.342/0.888 = 0.385 g water g^{-1} oil, or 0.385 litre water kg^{-1} of oil, or 385 g water kg^{-1} oil, or is (at a density of about 0.92 kg litre^{-1}) equivalent to 0.345 litre water litre^{-1} oil.

This value of course, **does not** reflect the real water requirements and water use of *J. curcas*, as transpiration for plant cooling and other processes, such as transport functions, require water as well. Unfortunately, no studies were found that reveal data on actual water use and crop production, as is the case in other crops, like cereals, where the production of 1 kg of grain requires roughly 1,000 litre of water.

Increased water use by the introduction of *J. curcas* trees, especially in large numbers, in hedges or in plantations, have not been studied so far. The effect of reduced soil evaporation due to increased shading and the presence of a mulch layer of senescent leaves and branches may still result in a negative water balance compared to the situation without *J. curcas*, as canopy transpiration will be increased considerably. This does not have to be problematic if no other competing claims draw on the available soil water reserves.

Potential evapotranspiration (PET) is a function of weather variables, such as solar radiation, air temperature, vapour pressure deficit and wind speed (Penman, 1956). An important variable to estimate the fraction of water evaporated by the soil and the fraction of water transpired by the crop is the leaf area index (LAI; m^2 leaf m^{-2} soil). On the one hand, LAI is an indicator for the extend of soil shading, and on the other hand it is an indicator for the number of stomata cavities in the leaf area through which gas exchange (CO_2 and H_2O) takes place for the photosynthesis process. A large canopy (high LAI) increases the transpiration rate considerably, even above PET values, whereas large LAI values may reduce the evaporation rate from the soil to almost zero (0).

One of the methods to estimate leaf area index of *J. curcas* at a given time is to consider the dimensions of singular leaves (Soares Severino *et al.*, 2007a), leaves per plant and plant density (PD) as in the equations below:

$$LAI = \left(\sum_{i=1}^{n} 0.84 \cdot (L_i \cdot W_i)^{0.99} \right) \cdot PD \qquad (r^2=0.99)$$

$$LAI = \left(\sum_{i=1}^{n} W_i^{1.87} \right) \cdot PD \qquad (r^2=0.97)$$

Where:
LAI = Leaf Area Index (m^2 leaf m^{-2} soil)
n = Number of leaves per plant (-)
L_i = Leaf length of i^{th} leaf (m)
W_i = Leaf width of i^{th} leaf (m)
PD = Plant density (plants m^{-2})

The above methods however, are very elaborative as they would require measuring each leaf of a number of plants individually. For calculating potential evaporation and transpiration, there is an obvious need for quick and easy assessment of leaf area index in *J. curcas* stands. The use of Leaf Area Index meters can be considered, such as the LI-COR Area Meters (LI-COR, Nebraska, USA) for fast, non-destructive leaf area measurements, or relations can be developed between leaf area and leaf weight, such as the Specific Leaf Area (SLA, cm^2 g^{-1}) or Specific Leaf Weight (SLW, g cm^{-2}). SLA and SLW may differ between *J. curcas* accessions and physiological age of the leaves.

Potential evapotranspiration (PET) may differ from actual evapotranspiration (AET), as the latter depends on soil moisture availability. Besides soil properties like soil depth, water holding capacity determined by soil texture and soil organic matter content, AET is determined by the dimension of the root system of *J. curcas* (rooting depth, lateral soil exploration and functional root surface), i.e. the ability of the roots to take up the available water in the soil over its rooting depth.

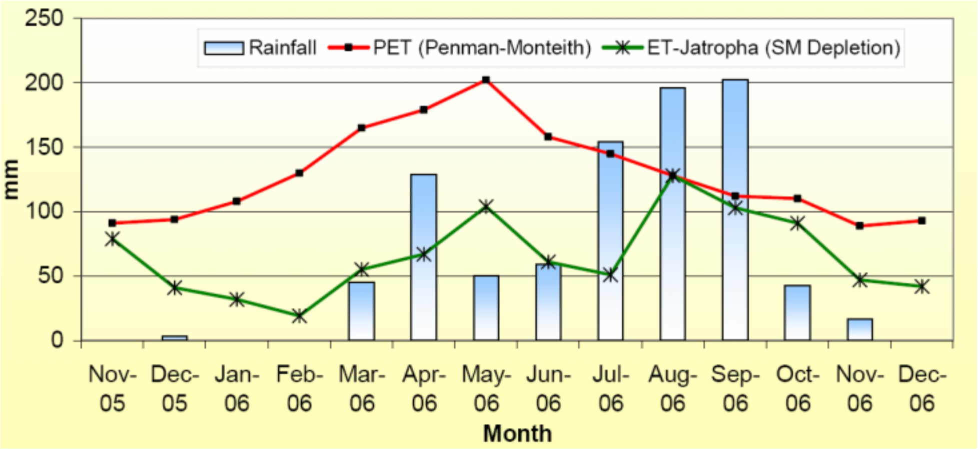

Figure 7. Water relations for the growth of a 2 years old J. curcas *plantation at ICRISAT India (Wan et al., 2007).*

In an example of a 2 year old *J. curcas* plantation in India, it becomes clear that soil water depletion mainly takes place when there is a substantial transpiring green canopy of *J. curcas* leaves (March-October) (Figure 7). During the sunny and hot months (March-June) the water request from the soil (PET) can not be fulfilled, as indicated by the actual soil moisture availability (SM Depletion). Evidently, precipitation (blue bars) is not sufficient to provide the requested amount of water to fulfil PET, and most probably, soil characteristics prevent the efficient storage and release of available rain water. In this case, the reduction of crop growth and production is substantial at a level of about 50%, indicated by the ratio AET/PET.

In another example (Figure 8), a 4 year virtual development of a *J. curcas* canopy (LAI) for Begui, Central African Republic (4° 14’ N, 18° 21’ E), with several water relations and effects on effective intercepted radiation is presented. In this example, monthly average climate data for 1961-1990 were used (New *et al.*, 2000). Due to soil conditions, Actual ET (represented by the cumulative black and green bars) is considerably lower than Potential ET (represented by the black line), with exception for the wet months March-November, as can be seen in the 3rd graph from the top. At increasing LAI, a larger fraction of ET is used for crop transpiration (green bars) and less for soil evaporation (black bars). In the 3rd and 4th year, the transpiration demand of the canopy (high LAI values), is larger than Potential ET. As a result, stomata in the leaves will close and the intercepted radiation can no longer be used effectively for the photosynthesis process. In the bottom graph of Figure 8 this is represented by the reduction of the effective intercepted radiation (brown bars), in comparison to the intercepted radiation (red bars).

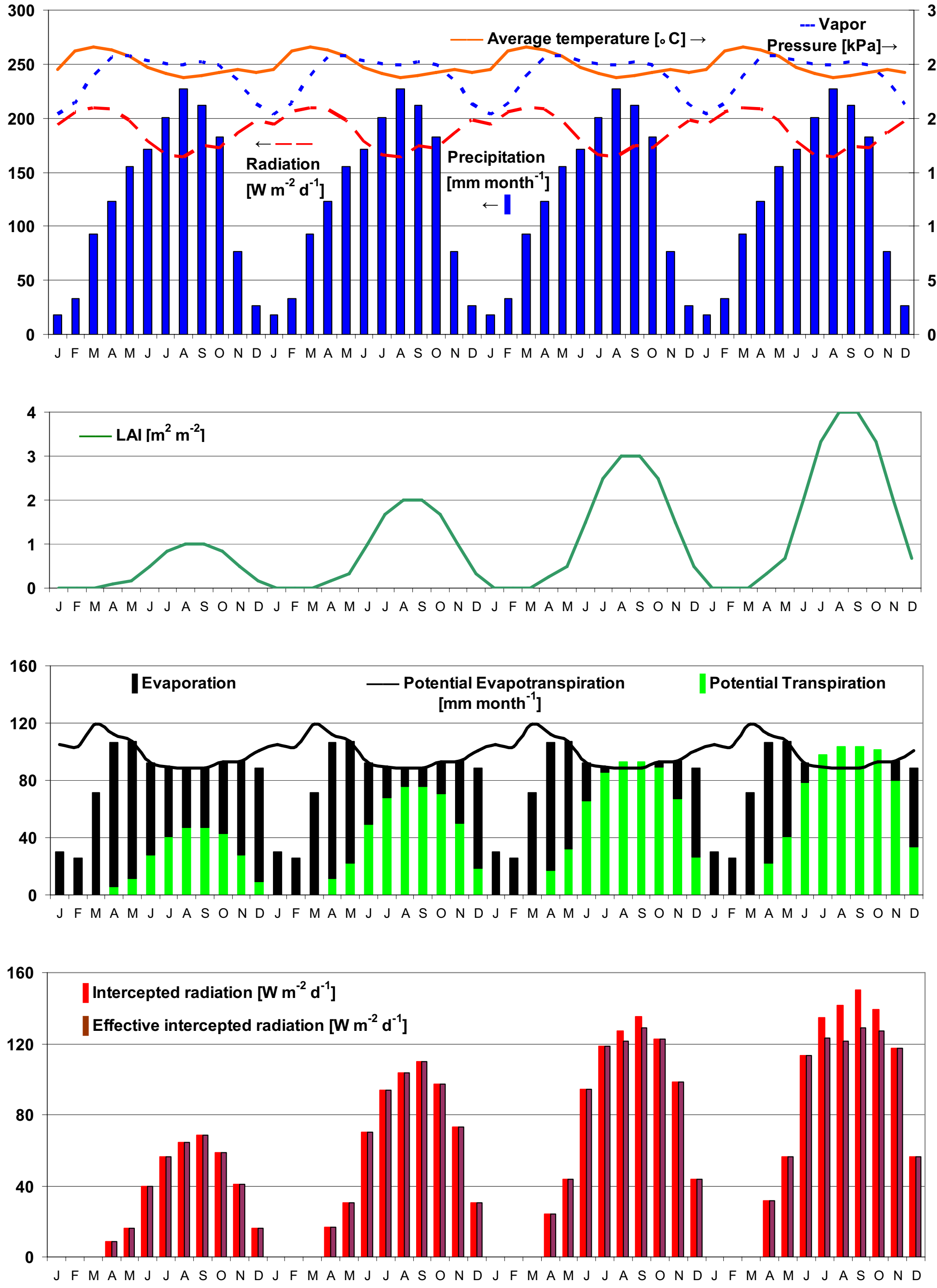

Figure 8. *4 years average climate data for Bangui, Central African Republic (4° 14' N, 18° 21' E) and the development of a virtual* J. curcas *canopy (LAI), with effects on evapotranspiration and (effective) intercepted radiation.*

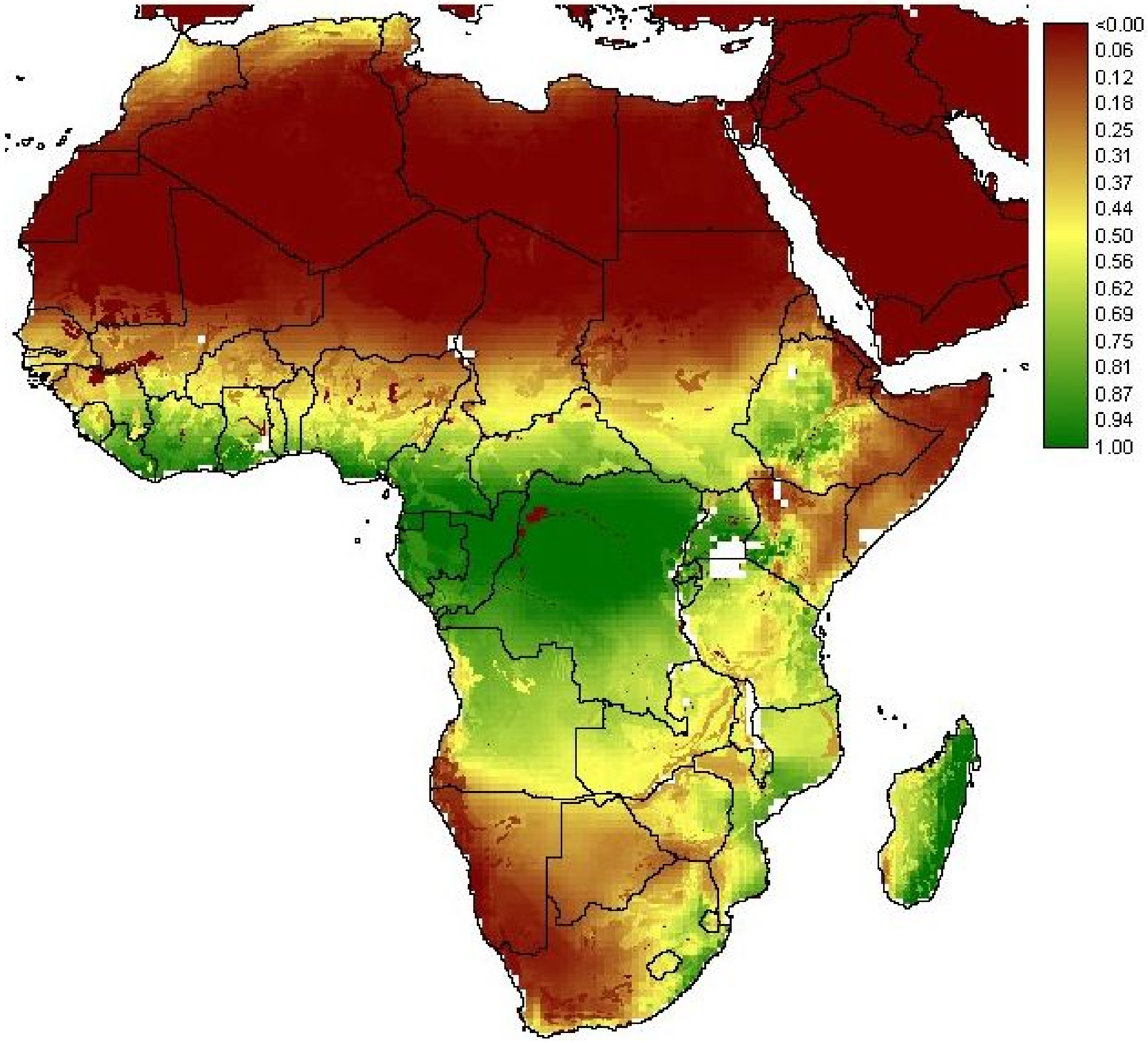

Figure 9. Yearly AET/PET calculations for Africa based on monthly average climate data and soil characteristics (calculations by Plant Research International, 2007).

In Figure 9, AET/PET ratios for Africa are presented by Penman-Monteith calculations based on monthly average climate data for 1961-1990 (New *et al.*, 2000). Actual evapotranspiration was calculated by taking into account soil properties, like water holding capacity and soil depth (Batjes, 2005), but not by considering crop growing seasons.

2.3 Low nutrient requirements

Like any other plant, *J. curcas* requires CO_2 from the air and H_2O from the soil for converting solar radiation in the photosynthesis process into functional carbohydrates (CH_2O). Adult leaves of *J. curcas* are well adapted to high radiation intensities as reported for experiments in Belize (Figure 10; Baumgart, 2007).

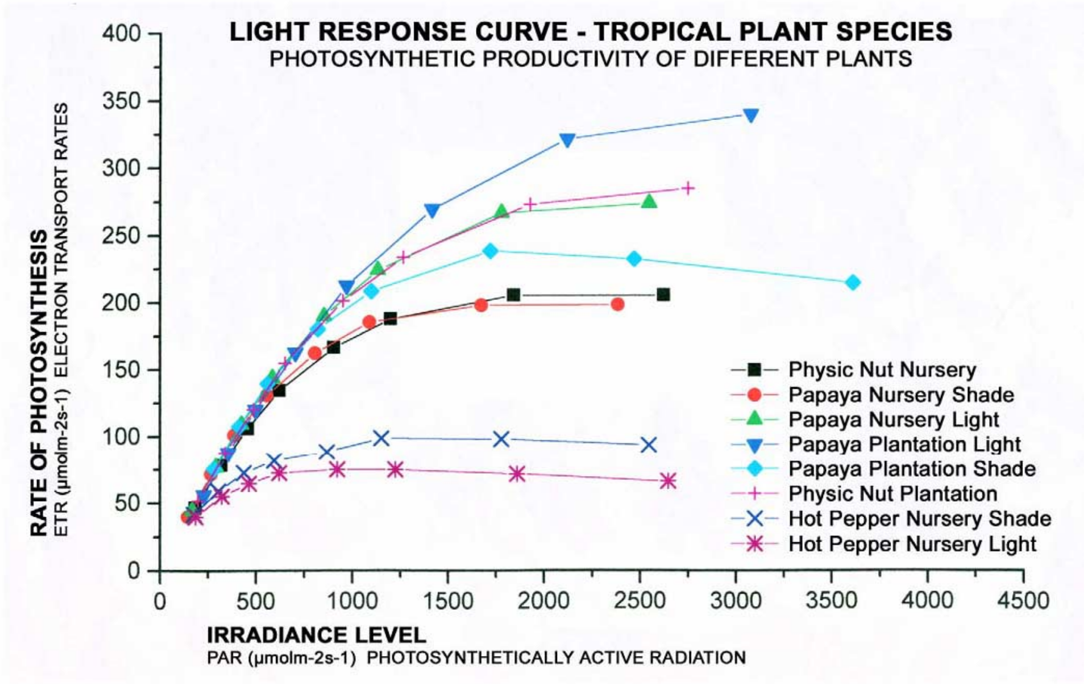

Figure 10. *Light response curve of* J. curcas *L. (Physic nut) in a nursery and in plantation compared to other tropical plant species in Belize (Baumgart, 2007; in collaboration with the Tree Physiology department of Albert-Ludwigs University Freiburg, Germany).*

Photosynthesis takes place in the nitrogen containing chlorophyll, predominately present in the green leaves. Nitrogen (N), Phosphorous (P) and Potassium (K) are key nutrients needed for the structural material of which roots, stems, branches, leaves, flowers, fruits and seeds are composed (Table 3).

The limitation of soil fertility (notable through limited availability of N, P and K in the root zone) hampers crop growth and crop production. Organic fertilizer (*J. curcas* seed cake) and plant density experiments (Density 1: 4x3 m (833 pl ha^{-1}) and Density 2: 3x2 m (1,667 pl ha^{-1})) in India indicated strong effects on crop growth and production after 2-2.5 years of growth. A *J. curcas* seed cake application of 3 t ha^{-1} resulted in 1.25 t seed ha^{-1} (Density 1; control 0.60 t ha^{-1}) and 1.45 t seed ha^{-1} (Density 2; control 0.75 t ha^{-1}) (Ghosh *et al.*, 2007). Fertilizer experiments on marginal lands in India with different levels of N (0-60 kg ha^{-1}) and P (0-30 kg ha^{-1}) applied at planting in a 2x2 m pattern (2,500 pl ha^{-1}), showed that plant height (1.97 m; +23%), leaf area index (1.1 m^{2} m^{-2}; +30%), total aboveground dry matter (9.5 t ha^{-1}; +32%), seed yield (0.44 t ha^{-1}; +72%) and oil yield (141.7 kg ha^{-1}; +76%) significantly increased at N45 fertilizer application in the 2nd year. For phosphorous applications, P20 yielded similar results (Patolia *et al.*, 2007a).

In the initial growth phase after establishment of a plantation, if there is no competition for radiation, water and nutrients between plants, nutrient content in mature leaves is not significantly affected by crop density. In the competition phase, in a range from 1,667-10,000 plants ha^{-1}, nutrient (N, P) content in leaves and nutrient (N, P) uptake from the soil was negatively correlated with plant density (Chaudharry *et al.*, 2007). In this situation, fertilization of *J. curcas* increased seed yield by 100%, either by inorganic or organic fertilizer fertilizer (Patolia *et al.*, 2007a; Patolia *et al.*, 2007b). Fertilization with *J. curcas* seedcake, the remaining bulk after oil pressing significantly increased seed yield (Ghosh *et al.*, 2007). Inoculation of *J. curcas* with mycorrhiza significantly increased the uptake of phosphorous (P) and micro-elements (Aluminium, Zinc, Chrome, Copper, Iron and Lead) from fly-ash (mineral residue from the combustion of coal in electric generating plants) (Sharma, 2007b).

Table 1. *Dry matter composition of* J. curcas *components.*

	Moisture (%)	Dry Matter (%)	Relative composition (%)	Oil content (%)	Source
Wood	15	85	25		Openshaw, 2000
Leaves			25		Openshaw, 2000
Fruit	8	92	50		Openshaw, 2000
	23	77			Sirisomboon *et al.*, 2007
Coat	85	15	30		Openshaw, 2000
	89	11			Sirisomboon *et al.*, 2007
			26		Mattana Saturnino *et al.*, 2005
Seed	3-7	93-97			Jones & Miller, 1992
				37.4	Kandpal & Madan, 1995
	5	95	70		Openshaw, 2000
				33.0-39.1	Ginwal *et al.*, 2004
			74		Mattana Saturnino *et al.*, 2005
Shell			34.7-41.6		Ginwal *et al.*, 2004
			34.3-46.1		Makkar *et al.*, 1997
	11	89			Vyas & Singh, 2007
	10	90	34.3		Openshaw, 2000
	10	90			Trabi, 1998
			37.6		Mattana Saturnino *et al.*, 2005
			29.9-31.9		Martínez Herrera *et al.*, 2006
Kernel			58.4-65.3	46.2-58.1	Ginwal *et al.*, 2004
			53.9-65.7		Makkar *et al.*, 1997
			65.7		Openshaw, 2000
				46.0-48.6	Kandpal & Madan, 1995
	3.0	97.0		48.5	Banerji *et al.*, 1985
	3.1-5.8	94.2-96.9			Trabi, 1998
	2.2-11.3	88.7-97.8	68.1-70.1		Martínez Herrera *et al.*, 2006
			62.4		Mattana Saturnino *et al.*, 2005
				21.0-74.0	Shah *et al.*, 2005

As a perennial crop, *J. curcas* invests a decreasing fraction of its carbohydrates into the wooden standing biomass over time, and if properly pruned, the seasonal requirements for nutrients are only needed for the seasonal formation of branches, leaves, flowers, fruits and seeds. If senescent plant material, like leaves, flowers and pruned branches are left in the field or incorporated in the soil as mulch, they are slowly decomposed, resulting in the release of the nutrients back into the soil where they are available again for crop uptake. The toxic components (phorbol esters) of *J. curcas* decompose quickly as they are very sensitive to elevated temperatures, light and atmospheric oxygen (NIH, 2007). Phorbol esters decompose completely within 6 days (Rug & Ruppel, 2000).

Table 2. Composition and energy content of J. curcas *components.*

			Ash (%)	Moisture (%)	Energy (MJ kg^{-1})	Source
Wood			1	15	15.5	Openshaw, 2000
Leaves						
Fruit			6	8	21.2	Openshaw, 2000
	Coat		13	15	11.1	Openshaw, 2000
	Seed		3.5-5.0	3-7		Jones & Miller, 1992
					20.8	Augustus *et al.*, 2002
			4	5	25.5	Openshaw, 2000
		Shell	4	11	16.9	Vyas & Singh, 2007
			5	10	17.2	Openshaw, 2000
				10	19.4	Trabi, 1998
		Kernel	3	3	29.8	Openshaw, 2000
			2.6-4.3	3.1-5.8	30.5-31.1	Trabi, 1998
				2.2-11.3	31.1-31.6	Martínez Herrera *et al.*, 2006
Plant oil					30.1	Makkar *et al.*, 1997
					37.8	Augustus *et al.*, 2002
					38.2	Pramanik, 2003
			<0.1	0	39.5	Francis *et al.*, 2005
					40.7	Openshaw, 2000
					41.8	Banerji *et al.*, 1985
					45.8	Forson *et al.*, 2004
Seed cake			4	3	25.1	

Table 3. Nutrient composition of J. curcas *components.*

			N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	B (ppm)	Na (ppm)	Source
Wood			3.34	0.09	2.87	0.30	0.26	0.12	55	99	2	605	10	134	[3]
Root			2.16	0.08	2.18	0.18	0.26	0.12	36	251	2	456	13	282	[1,3]
Leaves			6.40	0.34	2.45	1.40	0.53	0.19	28	168	6	117	71	808	[6][2]
			4.70	0.15	3.77	0.61	0.49	0.25	25	225	17	211	140	400	[1,3]
			1.23	0.33	2.17	5.04	1.19	0.13	15	245	7	119	23	398	[6][3]
			1.83	0.19	0.90	3.66	2.02	0.12	9	226	5	39			[4][1]
Fruit			2.15	0.05	0.73	0.44	0.30	0.10	22	40	11	25	4	28	[3]
	Coat		0.86	0.051	4.23										[4]
			0.19	0.041	2.35	0.18	0.06	0.03	4	31	2	35	6	142	[3]
	Seed			0.31											[2]
		Shell	0.70	0.047	1.58										[4]
			0.19	0.01	0.31	0.28	0.06	0.01	1	8	3	13	2	20	[3]
		Kernel	4.39	1.10	0.94	0.34	0.53	0.21	47	73	18	28	5	17	[1]
			1.96	0.49	0.42	0.15	0.24	0.09	21	33	8	13	2	8	
			2.53	0.37	1.25										[4]
Seed cake			3.82	1.75	1.44										[2]
			4.90	0.90	1.75	0.31	0.68	0.24	55	772	22	85	20		[3]
			6.40	2.80	0.95	0.65	1.35								[5]

Source: [1] Wan et al., 2007
[2] Jones & Miller, 1992
[3] Mattana Saturnino et al., 2005 ; Douradao Pacheco et al., 2007
[4] Chaudharry et al., 2007. [1] Leaves from 13 months old plants
[5] Francis et al., 2005
[6] Mattana Saturnino et al., 2005; [2] Mature leaves under the 1st raceme with flower; [3] old leaves

2.4 Jatropha as an energy crop

The harvested part of *J. curcas* is the fruit, mostly containing three seeds. The seeds make up circa 70% of the total weight of the fruit (30% fruit coat); the mature fruits have a moisture content of circa 15%, the seeds circa 7%. The oil is stored in the interior of the seed: the kernel, which makes up circa 65% of the total mass of the seed. The moisture contents are circa 10% for the hull and circa 5% for the kernel.

Note that in some publications it is not clear what is meant by 'seed': kernel and hull, which is the botanical seed (including the shell) or kernel only. Table 1 and Table 2 provide an overview of literature data on *J. curcas* components and dry matter distribution.

In the presented data the gross energy content ranges between 30.1-45.8 MJ kg^{-1} (Table 2), which leads to the assumption that the resulting oil pressings were not very pure, as the expected value of pure plant oil is about 45 MJ kg^{-1}. After pressing, up to 35% of fines (small impurities or sediment) may still be present in the pressing, which should be filtered out to increase the gross energy content per litre. Furthermore, the presented values for seed cake at 25 MJ kg^{-1} seem like a meal of crushed seeds, including the oil and not a de-oiled press cake.

Table 4. Typical oil extraction and global composition of other oil seeds.

Crop/product	Scientific name	Oil (%)	Protein in seed (%)
Castor bean	*Ricinus communis*	50	30
Coconut copra	*Cocos nucifera*	62	18
Cotton seed	*Gossypium spp.*	13	39
Groundnut kernel	*Arachis hypogaea*	42	26
Mustard	*Brassica spp.*	35	28
Oil palm kernel	*Elaeis guineensis*	36	2
Oil palm fruit	*Elaeis guineensis*	20	2
Rapeseed	*Brassica napus*	37	60
Sesame	*Sesamum indicum*	50	60
Soybean	*Glycine max*	14	40
Sunflower	*Helianthus annuus*	32	40

Note for comparison: soy bean oil and protein content together account for about 60% of dry soybeans by weight; proteins at 40% and oil at 20%. The remainder consists of 35% carbohydrate and about 5% ash. Palm oil content is about 56%; distributed as 36% from the palm kernel and 20% from the fruit coat. Proteins in palm oil are quite low. Typical oil extraction values and global composition of other important oil seeds can be found in Table 4.

Since *J. curcas* is considered a low input crop, implicating a low energy use for fertilisers, tillage and so on, the life-cycle carbon dioxide emissions for biodiesel can be low, likely less than 15% compared to petro-diesel (Francis *et al.*, 2005). This efficiency can still be improved by using the seed cake that remains after pressing or extraction of the oil for energy production.

2.4.1 Oil fraction and quality

The seed of *J. curcas* contains a viscous oil (Figure 6), highly suitable for cooking and lighting by itself and for the production of biodiesel. The total fraction of oil, fats and carbohydrates is circa 30 to 35% for the seed and, since 99% of the oil is stored in the kernel, circa 50 to 55% for the kernel (Table 1).

The oil contains very little other components and has a very good quality for burning. Cetane number of *J. curcas* oil (23-41) is close to cottonseed (35-40) and better than rapeseed (30-36), groundnut (30-41) and sunflower (29-37) (Vaitilingom & Liennard, 1997). The toxicity of *J. curcas* is mainly based on phorbol esters and curcains, which give no pollution when burnt. The oil is also very suitable for transesterification into biodiesel (Mohibbe Azam *et al.*, 2005). The absence of sulphur dioxide (SO_2) in exhaust from diesel engines run on *J. curcas* oil shows that the oil may have a less adverse impact on the environment (Kandpal & Madan, 1995). As *J. curcas* oil has a higher viscosity than diesel oil (53 versus 8 cSt at 30 °C), blending *J. curcas* oil up to 50% with diesel oil is advised for use in a Compression Ignition (C.I.) engine without major operational difficulties (Pramanik, 2003). Other publications mention much lower values for viscosity (17.1 cSt at 30 °C), which would reduce the necessary blending fraction of diesel oil (Akintayo, 2004), however, conventional engines can be operated by blending biomethanol or bioethanol (with gasoline) or bio-diesel (with diesel) from 3-20%. Some report that *J. curcas* oil should only be used as ignition-accelerator (Forson *et al.*, 2004).

2.4.2 Seed cake

Like the oil, the seed cake is toxic and therefore only suitable as animal feed after processing. The toxicity of *J. curcas* is based on several components (phorbol esters, curcains, trypsin inhibitors and others) which make complete detoxification a complicated process. Detoxification has been successful at laboratory scale (Gross *et al.*, 1997; Martínez Herrera *et al.*, 2006), but since the process is complicated, it is not suitable for small scale and local use. Large scale feed production, however, has to compete on a global market with high quality demands. Therefore, detoxification must be complete, constant and guaranteed, and is thus expected to be expensive. Hence, a successful penetration of *J. curcas* seed cake as feed to the market at a profitable price seems doubtful.

The main toxic components are phorbol esters, although in Mexico accessions without, or with low content of phorbol esters have been found (Rivera Lorca & Ku Vera, 1997; Martínez Herrera *et al.*, 2006; Basha & Sujatha, 2007). The seed cake of this so called 'non' or 'low' toxic variety might be suitable for use as animal feed, but it still contains minor quantities of toxic components and resistance on the feed market towards this product is to be expected.

On the other hand, the seed cake is nutrient rich and therefore very suitable as fertiliser (Table 3). Together with the fruit coats, the major part of the nutrients can be recycled. When no fertilisers are used, which is assumed to be the case in the use of *J. curcas* as a low input crop, this recycling is necessary to maintain soil fertility, especially on non fertile marginal lands. Patolia (2007a) reported total aboveground dry matter increase of 24% after 2 years N_{45} application, compared to N_0 treatment (7.7 t dry matter ha^{-1}) and a yield increase of circa 100% in *J. curcas* when 3 t seed cake ha^{-1} was used as a fertiliser on *J. curcas* stands at a densitu of 4x3 m (1.52 t seed ha^{-1}) and at 3x2 m (0.87 t seed ha^{-1}) on marginal land (Ghosh *et al.*, 2007). This yield increase was comparable with the increase reached with optimized mineral doses of N (45 kg ha^{-1}) and P (30 kg ha^{-1}) for stands of 1,667 pl ha^{-1} (Patolia *et al.*, 2007a). Because of unavoidable inefficiencies, recycling nutrients will only be effective at a certain production level that allows a high dynamic nutrient cycle to take place. Initiating a plantation on low or non fertile soils therefore implies the need to use other fertilisers, at least at the start, to boost crop growth and seed production in the initial stages.

The by-products of *J. curcas*, such as fruit coats, seed hulls and the remaining de-oiled seed cake after pressing, may be used for organic fertilization, or for the production of more energy. Seed hulls can be burnt and the seed cake and fruit pulp can be used for the production of biogas by anaerobic fermentation (López *et al.*, 1997; Staubmann *et al.*, 1997; Vyas & Singh, 2007). By burning, most nutrients will be lost, but after fermentation, most nutrients will remain in the effluent that can still be used as a fertiliser to recycle nutrients. To maintain *J. curcas* production at a sustainable level, it is important to be aware that a huge amount of nutrients are removed if *J. curcas* by-products are exploited for additional valorisation. However, the range in the reported nutrient values only comes from a few sources (Table 3), with clear variation. This indicates that environmental and management conditions have a large effect on the eventual nutrient content of the various plant parts. Soil organic matter content decreases in a production system where nutrients are removed and not replenished by fertilization.

2.5 High oil yield

The positive claims on *J. curcas* high oil yields seem to have emerged from incorrect combinations of unrelated observations, often based on measurements of singular and elderly *J. curcas* trees. Extrapolation of such measurements to larger areas with *J. curcas* as a monoculture crop (or in intercropping systems), ignores the growth reduction in such systems occurring from the competition for natural resources, such as radiation, water and nutrients.

2.5.1 Flowering and pruning

J. curcas is a monoecious shrub or small tree, with staminate (male) flowers and pistillate (female) flowers on the same inflorescence (raceme). The inflorescence is a panicle, with the female flowers (about 10-20%) at the apices of the main stem and branches of the inflorescence (Figure 11). Male flowers are more numerous (about 80-90%) and occupy subordinate positions on the inflorescence. There is a strong correlation between reproduction and vegetative growth, revealed by the total number of flowers produced and the total length of the branches, bearing the inflorescence at their tips (Aker, 1997). Proper pruning (2/3 of the branch in the dormancy phase, when leaves are shed) seems to be an efficient technique to induce further branching. In India it was essential to pinch the apex of 6 months age at 0.30 m to induce branching, slower growing provenances could be cut at 0.45 m (Sharma & Sarraf, 2007b).

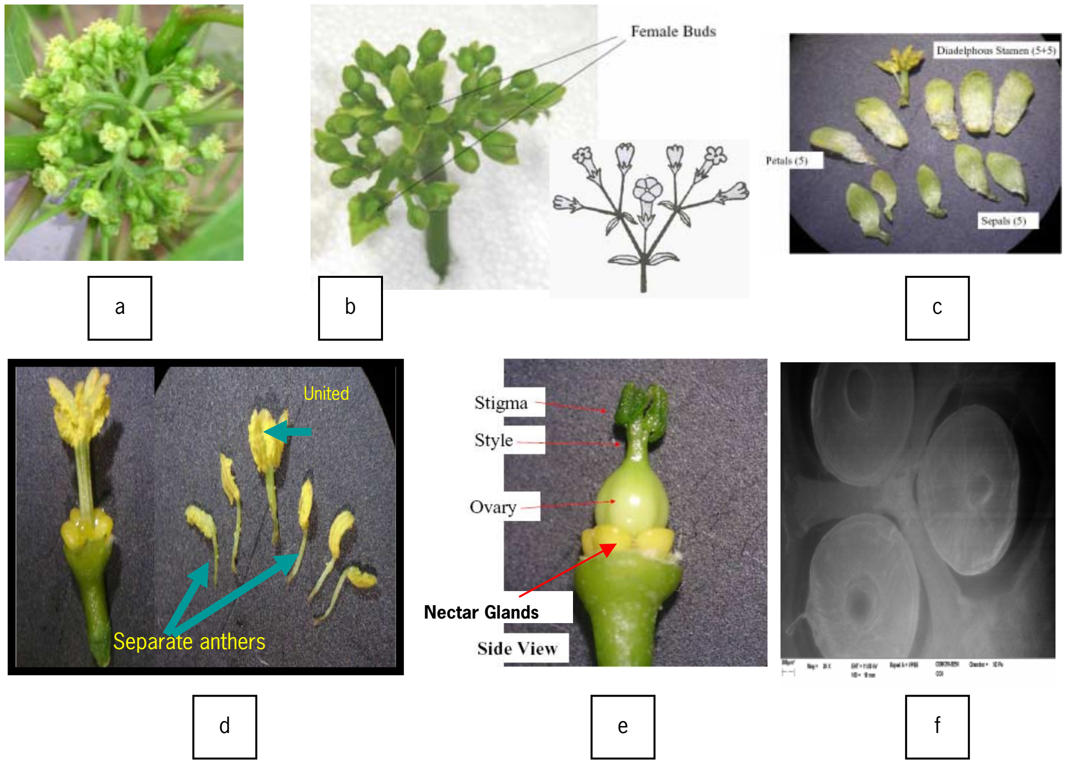

Figure 11. J. curcas *flowers: a-b) female flowers and buds at apices, c) petals, sepals and diadelphous stamen, d) anthers, e) ovary and nectar glands, and f) electron- microscope vision of triple seed setting in the fruit (Source: Prakash et al., 2007).*

Flowering is one of the most important crop phenological stages for *J. curcas* oil production, as the number of female flowers and their fertilization determines how many fruits and seeds eventually will develop. Flowering normally starts after a dry and dormant period and is induced and continued by prolonged periods of soil water availability, either by precipitation or irrigation. Male flowers open for a period of 8-10 days, whereas female flowers open for 2-4 days only (Prakash *et al.*, 2007). Nutrient limitation seem to provoke the end of flowering (Aker, 1997). Continuous flowering results in a sequence of reproductive development stages on the same branch, from mature fruits at the base, to green fruits in the middle, and flowers at the top of the branch. This is problematic for mechanized harvesting.

Small flowers and abortion of flowers and fruits may be as large as 60% or more, depending on soil water and nutrient availability. If carbohydrates are insufficiently produced, e.g. in the first period after dormancy, flower abortion is a common phenomenon in India (Kumari & Kumar, 2007). Some experience with the application of plant hormones (auxines NAA and IAA) increased biomass yields. The application of the plant hormone GA3 induced flowering (Kumari & Kumar, 2007).

2.5.2 Seed oil content

The high oil contents of seeds that have been observed in various *J. curcas* accessions (Table 1) have added to the high expectations of oil yield production on a hectare base. However, the observed variation is large, whereas the genetic base is considered small in India (Basha & Sujatha, 2007). Reported values for seed oil content apply to: 1 accession from India: 37.4%: Kandpal & Madan, 1995; 10 accessions from India, 33-39%: Ginwal *et al.*, 2004; 6 trees in India, 23-45% (kernels): Pant *et al.*, 2006; 23 accessions from India: 26-35% Patolia *et al.*, 2007b; 7 provenances from India: 29-39%: Sharma, 2007a; 24 accessions from India: 28-39%: Kaushik *et al.*, 2007; 4 out of 11 provenances from India: >35%: Kumar & Kumari, 2007; 10 provenances from Indonesia: 28-34%: Manurung, 2007; 8 provenances from India: 28-36%: Shekhawat *et al.*, 2007 (See Table 1).

Without any doubt, high oil content of the seeds is an important crop characteristic, but if seed size, the number of seeds, or the number of fruits per tree (or per square meter) is not accurately accounted for, oil yields per hectare are easily overestimated. In the same way, *J. curcas* accessions that produce large seeds, and a high number of seeds or fruits per tree (or per square meter), may be low in oil production per hectare if seed oil content is low. In the ideal situation with a high number of seeds per plant (or per hectare) in combination with high oil content per seed, it is justified to relate high oil yields with *J. curcas*. All studies that express seed yield (or oil yield) per tree should therefore be carefully analyzed and valued.

2.5.3 Seed yield

Seed yield in *J. curcas* varies widely, which is logic for a crop that can grow under many different conditions. For hedges in Mali, the values of 0.8 to 1.0 kg dry seed per meter of hedge is often cited (Henning, 1998), but this range is so small that it is unlikely that these values include really different conditions (climate, soil) or situations (e.g. age, number of plants m^{-1}, etc.).

Seed yield can also be highly variable within plantation stands, varying for example from 0.2 to more than 2 kg per tree (Francis *et al.*, 2005). This variability in yield is in contrast with the genetic variability, which is rather small in Indian germplasm (Basha & Sujatha, 2007).

Recently published low production figures mostly apply to young *J. curcas* plantations of 1-2 years old. *J. curcas* is known to grow and produce with a minimum water availability of 500 to 600 mm y^{-1}, with a realistic yield of probably less than 1 t seed ha^{-1} (Euler & Gorriz, 2004). Optimal growth seems possible with a water availability of 1,200 to 1,500 mm y^{-1}, if it is well distributed. In Brazil, at different plant spacing and with drip irrigation, yields were 335 kg seed ha^{-1} (4x3m; 833 pl ha^{-1}; after 12 months), 190 kg seed ha^{-1} (8x2m; 625 pl ha^{-1}; after 9 months) and 56 kg seed ha^{-1} (8x2m; 625 pl ha^{-1}; after 7 months) (Mattana Saturnino *et al.*, 2005). In India, experiments on marginal soils yielded 0.60 (control, 833 pl ha^{-1}) to 1.45 t seed ha^{-1} (1,667 pl ha^{-1}) after 2.5 years (Ghosh *et al.*, 2007). In Indonesia, the first year's yield of a plantation resulted in ca. 3.0 t seed ha^{-1} (Manurung, 2007). Yields were reported ranging from 3.2 to 4.1 t seed ha^{-1} for the first year after planting for six different locations of rain fed marginal lands in Uttar Pradesh (India), unfortunately without detail on growth conditions and management (Lal *et al.*, 2004).

Note: For reported yield values it is not often clear if values apply to fresh or dry weight (and how dry weight is expressed), and if the whole fruit, the complete seed with its kernel, or the kernel alone is meant. The oil contents in *J. curcas* seeds show a high variability (Table 1) and, since the oil content seems not to be related with the seed yield (Patolia *et al.*, 2007a), this variability may be a good criteria for selection.

2.5.4 Genetic and environmental effects

Genetic and environmental factors have significant impact on oil yield production factors. Within the (perhaps small) genetic resource base of 24 *J. curcas* accessions from Haryana state (India), environmental factors were predominant over genetic factors, although seed size, and oil content and seed weight could be genetically clustered and significantly differentiated (Kaushik *et al.*, 2007). In another (small) sub-set of 10 *J. curcas* accessions from Central India, seed oil content was significantly correlated (** at 0.01 level) with seed weight (0.792**), stem diameter (0.836**) and total leaf area (0.883**) (Ginwal *et al.*, 2004). In a range from 400 to 1,000 m elevation, that might have a relation with temperature, altitude had a significant positive effect on various oil yield components, including the number of branches per tree (+2), number of fruits per branch (+12), number of fruits per tree (+100) and number of seeds per tree (+300), but a significant reduction was observed in kernel oil content (43.10 at low vs. 30.66% at higher elevations) (Pant *et al.*, 2006). Kernel oil content was significantly higher in soils that had not been used for arable farming before (42.3 vs. 35.0%), but no information on soil fertility variables were presented

(Pant *et al.*, 2006). Reported values of seed weight vary considerably for different *J. curcas* provenances (Table 1). Reported genetic factors included seed weight and seed oil content (Ginwal *et al.*, 2004; Kaushik *et al.*, 2007), although 42 Indian accessions of *J. curcas* showed modes levels of genetic diversity with 400 RAPD (Random Amplification of Polymorphic DNA; genetic fingerprinting technique) 42% molecular polymorphism) and 100 ISSR (Inter-Simple Sequence Repeat: genetic fingerprinting technique) (33.5% molecular polymorphism) primers (Basha & Sujatha, 2007). In other tests with 23 selected provenances from 300 collected provenances in India, 8-10% (AFLP; Amplified Fragment Length Polymorphism; genetic fingerprinting technique) and 14-16% (RAPD) polymorphism was found (Reddy *et al.*, 2007).

2.5.5 Seed yield projections

Projections for more mature plantations lack a sound scientific basis, or worse, are based on wrong assumptions. Values from 0.4 to 12 t seeds ha^{-1} per year were projected for mature plantations (Jones & Miller, 1992), but no information on the background of this variation was given. A range of 0.5-12 t ha^{-1} and 5 t ha^{-1} as a reasonable estimate for good soil conditions under rainfall conditions of 900-1,200 mm y^{-1} was reported without evidence (Francis *et al.*, 2005; Daey Ouwens *et al.*, 2007). Openshaw (2000) anticipated yields of 7.5 t fruits ha^{-1} y^{-1} (circa 5 t seed ha^{-1}) for an established stand under good growth conditions with sufficient water, but without presenting the scientific basis.

From plant physiological point of view, plant growth is a function of intercepted photosynthetically active radiation (PAR), temperature and water availability, provided that nutrient levels are at sufficient level. Based on the global distribution of these variables, Net Primary Production (NPP, g C m^{-2} y^{-1}) can be calculated as the production of all types of plant biomass in a year (Figure 12).

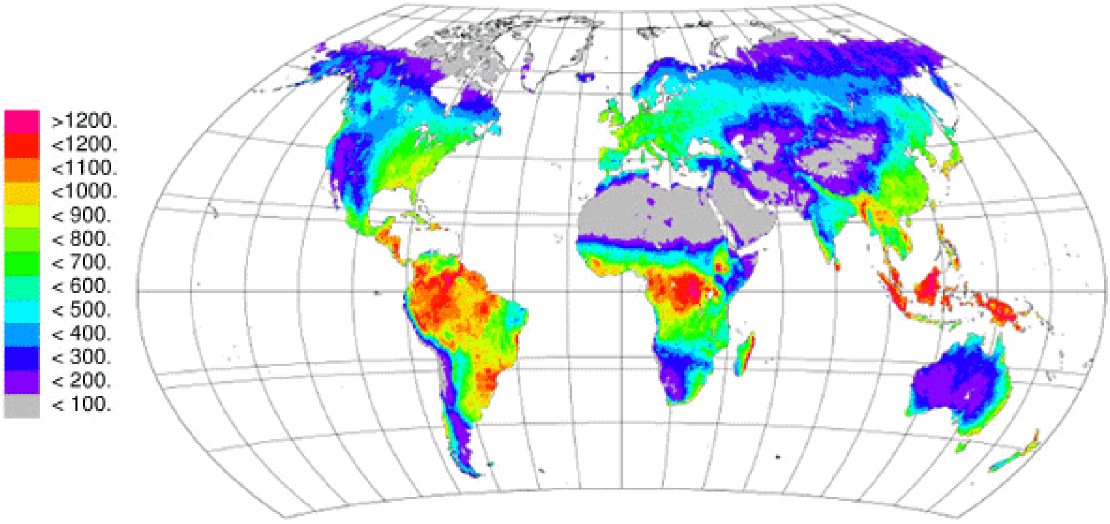

Figure 12. Annual net primary production (NPP, g C m^{2} y^{-1}) estimated by different simulation models (Sahagian & Hibbard, 1997).

Looking at latitude distribution of Net Primary Production and the *J. curcas* belt (roughly between 30° N and 35° S, Figure 13), simulated values for NPP vary between 200 and 1,000 g C m^{-2} y^{-1} (equal to 2 to 10 t C ha^{-1} y^{-1}). As the average carbon (C) content of plant material is about 47.5% of total dry matter (Ho, 1976), resulting NPP ranges between 4.4-22.2 t dry matter ha^{-1} y^{-1} in the *J. curcas* belt, depending on longitude and the applied simulation model.

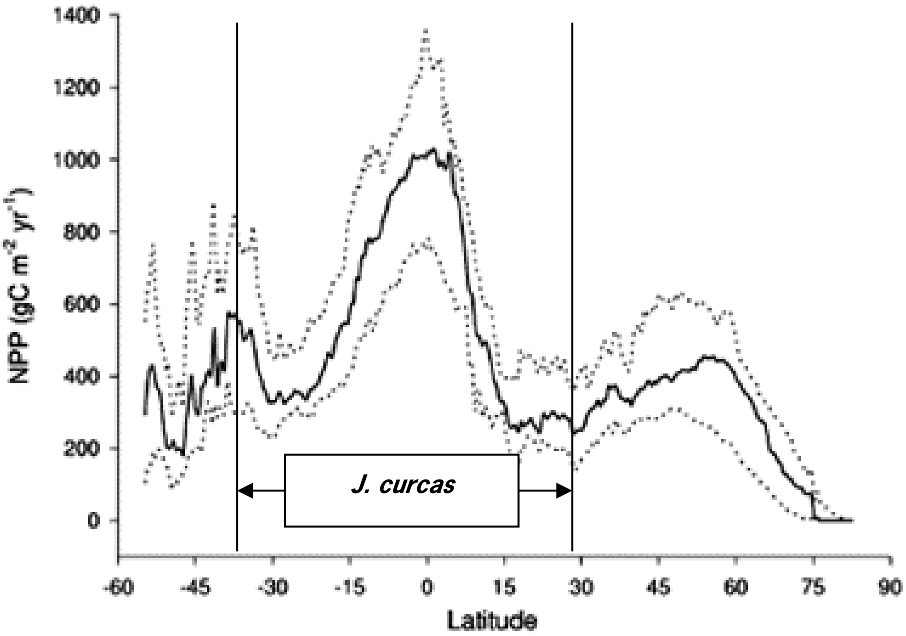

Figure 13. *Net primary production (NPP, g C m^{2} y^{-1}) depending on latitude, estimated by model simulations (adapted from Sahagian & Hibbard, 1997). The bold line indicates average values; the dashed lines indicate variation by longitude and by the application of different simulation models.*

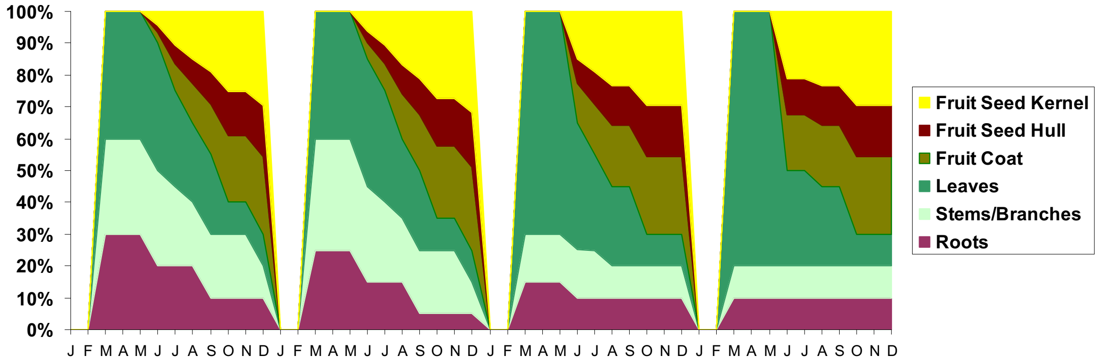

Figure 14. *Theoretical (!) evolution of* J. curcas *dry matter assignment to roots, stems and branches, leaves, fruit coats, seed hulls and kernels, for a period of 4 years (reaching maturity).*

Assuming a mature *J. curcas* stand that intercepts all incoming radiation, 25% of dry matter is accumulated in wood (stems and branches), 25% in leaves and 50% in fruits (Openshaw, 2000). These values for dry matter distribution among plant organs are indicative values and are debatable, as no proper growth analyses have been reported so far. A theoretical distribution of dry matter distribution is presented in Figure 14, where (over years) relatively less dry matter is assigned to roots and stems, and more to leaves and fruits.

However, if a distribution of 30% fruit coat and 70% seeds is assumed, as found by various authors (Table 1), seed production for a mature *J. curcas* stand may range between 1.5-7.8 t dry seed ha^{-1} y^{-1}. An assumed seed oil content of 35% would result in 539-2,720 kg extractable oil ha^{-1} y^{-1}. An extraction efficiency of 75% would lead to 404-2,040 kg oil or (assuming an oil density of 0.92 kg litre^{-1}) about 439-2,217 litre oil ha^{-1}. In the above example, the Harvest Indices (HI) for various components per kg dry seeds are:

- HI_{SEED} ≈ 0.35 kg kg^{-1}
- $HI_{OILWEIGHT}$ ≈ 0.09 kg kg^{-1}
- $HI_{OILVOLUME}$ ≈ 0.10 litre kg^{-1}

Note that these projections apply for the situation that all incoming radiation is intercepted (which is not the case if there is a distinct growing season (green leaf period) for *J. curcas*), and that local differences may result from genetic and environmental conditions that affect dry matter distribution among plant organs.

The argumentation above may explain the difference with a high yielding oil crops such as oil palm (production up to 5-6 t oil ha^{-1} y^{-1}), that gradually decreases dry matter assignment to leaves and stems over time (Tinker & Smilde, 1963; Gerritsma & Soebagyo, 1999). The dry matter assignment to the oil seed is more positive for oil palm. The continuous high value for leaf area index (LAI) in oil palm guarantees year-round full interception of incoming radiation, and secures high production potentials (Gerritsma & Soebagyo, 1999). The oil palm belt, roughly situated between the latitudes of 10° N and 10° S, shows highest radiation and temperature levels, resulting in a higher NPP potential in comparison to other latitudes (See Figure 12 and Figure 13). Furthermore, the humid climate conditions in oil palm production areas prevent water shortage situations, and the acknowledgement of the importance of soil fertility (oil palm production on fertile soils) result in higher oil production values for oil palm than from *J. curcas*.

However, *J. curcas* potential for annual oil production (439-2,217 litre ha^{-1}) is high in comparison with values reported for other oil producing crops, like soybean (375 litre ha^{-1}), sesame (575 litre ha^{-1}), sunflower (800 litre ha^{-1}), rapeseed (1,000 litre ha^{-1}) and castor (1,200 litre ha^{-1}), although these values may double or triple in the case of double or triple growing seasons in a year. One of the competitive aspects of *J. curcas* is the perennial growth (with its positive effects on soil conservation), with a relative high Harvest Index for seed (HI_{SEED}≈0.35) and oil (HI_{OIL}≈0.10).

2.5.6 Yield improvement

To increase oil yield, agronomic practices and crop management should be aimed at optimizing the use of (natural) resources like solar radiation, water and soil fertility, and the prevention of pests and diseases.
In the initial growth phase after establishment of a plantation, when there is no competition for radiation, water and nutrients between plants, seed yield per plant and seed yield on an area base is not significantly affected by crop density. In the competition phase, seed yield per plant is negatively correlated with plant density, but seed yield on an area base is positively correlated with plant density (Chikara *et al.*, 2007). As a comment to the latter observations, it should be noted that plant density may not be a fully explanatory variable, as additional branching in low plant density situations, may increase the number of fruits per area base considerably. Data on branching however, were not reported for this situation (Chikara *et al.*, 2007).
A prerequisite for better growth and production may be the presence of arbuvescular mycorrhiza in the soil for the uptake of phosphorous (P), which have been reported to reduce P deficiency on marginal soils (Sharma, 2007b).

The dry matter distribution ratio between fruit coat and seeds might be good selection criteria for increasing seed yield, as well as finding *J. curcas* accessions that assign more dry matter to fruits instead of stems and leaves. Since the oil content seems not to be related with seed yield (Patolia *et al.*, 2007b), this variability may be a good criteria for selection as well.

2.5.7 Summary

Recently published low production figures mostly apply to young *J. curcas* plantations of 1-2 years old. Currently observed yields range from 0.6 to 4.1 t seed ha^{-1} if proper attention is given to crop establishment, water and fertility levels. Depending on crop growth conditions, such as water, nutrient availability and the absence of plagues and diseases, maximum yields of 7.8 t seed ha^{-1} are projected for mature stands. Depending on geographical distribution, *J. curcas* stands may reach maturity and full production about 3-4 years after planting. Younger stands have appreciably lower yields due to inefficiencies in radiation interception and the assignment of dry matter to standing biomass instead of the harvestable parts, the fruits and seeds. Decreasing productivity has been reported for aging stands, but it is not clear whether this is a general phenomenon or not. A reason for declining productivity could be the increasing pressure of fungal diseases, likely to occur under high rainfall and humid conditions. Pruning and use of fungicides might abate the decline in yield, but quantitative data are not available.

Data on production levels under well defined sub-optimal growth conditions are largely absent. This makes it practically impossible to predict future production potentials from marginal land, while especially the production on marginal land can contribute to the development of rural areas without competing much with food production and biodiversity. It can be stated that the hype in *J. curcas* oil production is not sufficiently supported by hard data on crop production, well controlled or optimal management production conditions, and environmental impact (Achten *et al.*, 2007; Muys *et al.*, 2007).

2.6 Oil recovery

Figure 15. Examples of a Bielenberg Ram Press and a commercially available pressing system for J. curcas *seeds.*

For *J. curcas* oil extraction at small scale, various oil presses have been developed and modified from presses for other oil seed crops. They have in common that they vary in design and are non-standardized, as they were originally developed for other (edible) seeds and need to be optimized for *J. curcas* seeds. *Bielenberg Ram (Hand) Presses* handle 7-10 kg seed h^{-1} and spindle presses handle 15 kg seed h^{-1} (Mbeza *et al.*, 2002). Commercially available pressing systems claim processing 500 kg seed h^{-1} (Figure 15).

The recoverable oil fraction is clearly affected by pressing technology. For hand powered small scale pressing (such as the *Bielenberg (Hand) Ram Press*), an oil yield of only 19% of the seed dry weight or 30% of the kernel was reported (Foidl & Eder, 1997; Augustus *et al.*, 2002; Akintayo, 2004; Henning, 2004; Francis *et al.*, 2005), which is about 60% of the total extractable amount. With mechanized pressing equipment about 75% of the oil can be recovered. Commercially available pressing systems used for large-scale de-oiling of e.g. soybean and rapeseed reach up to 90%.

Modern extraction techniques can substantially raise the extractable oil fraction. Industrial extraction with organic solvents (mainly hexane) yield near 100% of the oil content, while extractions on water basis can yield from 65-97% of the oil, depending on, (a.o.) the composition of the extract solvent, the acidity (pH) and the temperature of the solvent (Shah *et al.*, 2004; Shah *et al.*, 2005).

2.7 Low labour input

It is unverified that *J. curcas* oil production requires minimum amounts of labour input. The claim that it would be an excellent choice in areas that have low labour capacity should therefore be strongly defied. Also, the noble thought of generating income in HIV-affected communities by planting *J. curcas* as a low labour input crop, cannot be sustained. In order to prepare the land, set-up nurseries, plant, irrigate, fertilize, prune, harvest and process the seeds for oil production, labour availability and labour costs are elements to be seriously accounted for, especially in the 1st year for establishment of the crop. Labour needed for crop maintenance and harvest will increase to substantial levels in the subsequent years. The required labour input may be at a modest level only when *J. curcas* is used for combating desertification, conserving water and preventing soil erosion, because crop maintenance, harvesting and processing is not required. The use of *J. curcas* in Contour Vegetation Barriers (CVB) as an example of such a soil and water conservation measure in Burkina Faso and Mali - West Africa (rainfall up to 1,200 mm y^{-1}), has been found effective. The labour requirement for 100 m CVB was calculated as 30 man-days per year (Spaan *et al.*, 2004). The locally available *J. curcas* genetic resources however, were not suitable to integrate the soil and water conservation function with oil production at the same time (Wiesenhütter, 2003). Labour input for crop maintenance, (weeding, irrigation, fertilization, pruning) increased from 22 person days ha^{-1} y^{-1} in the 1st year, to 70 person days ha^{-1} y^{-1} (including harvesting) in the 6th year (Sharma & Sarraf, 2007c).

2.8 Competing claims between food and bio-fuel production

The raised expectations of *J. curcas* oil production may result in a doubtful incentive for farmers to change from traditional or commercial food production to bio-fuel production. In both cases, farmers may risk their food security or income stability.

Until *J. curcas* oil production has proven to be sustainable at a reasonable level, with transparent and fair market opportunities, or by opportunities for local use of *J. curcas* oil in lighting, electricity, cooking and mechanization, risk avoidance strategies in crop production may be required. An option would be to integrate *J. curcas* production in traditional farming systems, such as intercropping or hedge production.

If *J. curcas* sustainable oil production is considerably raised and stable, farmers may choose to dedicate their soils, labour efforts and money in *J. curcas* production. The impact of such a shift from food production to bio-fuel production is unpredictable, as it depends on the availability of natural resources and the competition emerging from the incorporation of this crop in the food production systems.

2.9 Tolerance to pests and diseases

The assumed tolerance of *J. curcas* to pests and diseases that have been reported are merely based on observations of singular and solitary trees, and do not apply in general to *J. curcas* grown in plantations.

The toxic characteristics of *J. curcas*, caused by constituents in leaves, stems, fruits and seeds may suppress damaging effects from some predators, but certainly not all. In plantations, especially under humid conditions, serious problems have been reported with fungi, viruses and the attack of insects (Sharma & Sarraf, 2007a). Observed diseases are 'Collar rot' (caused by *Macropphomina phaseolina* or *Rhizoctonia bataticola*) at juvenile stages or by water-logging at adult stages, Leaf spots (caused by *Cercospora jatrophae-curcas*, *Helminthosporium tetramera* or *Pestalotiopsis spp.*), Root rot (caused by *Fusarium moniliforme*) and damping off (caused by *Phytophtora spp.*).

2.10 Nutritive potential and toxic constituents

Great variation is observed in seed kernel fraction (Makkar *et al.*, 1997: 53.9-64.0%; 61.3±3.1%) relative to the whole seed (Makkar *et al.*, 1997). Within the kernel there is subsistent variation between provenances in crude protein (19-31%; 26±3.2%), lipid (43-59%; 53±4.8%), neutral detergent fibre (3.5-6.1%; 5.0±0.87%) and ash

(3.4-5.0%; 4.2±0.52%) (More observed values in Table 5). Gross energy content of the kernels ranged between 28.5-31.2 MJ kg^{-1} (30.1±0.8 MJ kg^{-1}) (a.o. Makkar *et al.*, 1997) to 45.8 MJ kg^{-1} (Forson *et al.*, 2004), mostly as a result of the debris fraction in the oil after pressing. See Table 2 for more values.

A wide variation in toxic constituents, e.g. trypsin inhibitor in defatted kernels (18.4-27.5 mg g^{-1}; Makkar *et al.*, 1997) was observed, as well as a wide variation in saponins (1.8-3.4%; Makkar *et al.*, 1997) and phytate (6.2-10.1%; Makkar *et al.*, 1997). Phorbol esters are predominantly present, but are sometimes at low levels or not detected in provenances from Mexico. Phorbol ester content ranged from 0.87-3.32 mg g^{-1} of kernel weight in 17 provenances (Makkar *et al.*, 1997; 3.85 mg g^{-1}: Martínez Herrera *et al.*, 2006).

Much attention to various aspects and tests of toxic components (phorbol esters and curcain) in *J. curcas* was reported at the 'Jatropha 97' Symposium in Managua, Nicaragua (Chapter 4 in Gübitz *et al.*, 1997), including experiences for using proteins from toxic and 'low toxic' *J. curcas* seeds for livestock feed (Makkar & Becker, 1997). Toxic constituents were found to be effective against a wide variety of pests (Solsoloy & Solsoloy, 1997; Rug & Ruppel, 2000). A 100% mortality rate was obtained against mosquito (*Culex quinquefasciatus* Say), when petroleum extracts of *J. curcas* leaves were used as a larvicide (Karmegam *et al.*, 1997).

Table 5. Nutritive values for J. curcas components.

			Oil (%)	Crude Protein (%)	Lipid (%)	Crude fibre (%)	Source
Wood							
Leaves							
Fruit							
	Coat						
	Seed		33.6-37.0			10.6-11.5	Rivera Lorca & Ku Vera, 1997
				38.38		22.88	Mattana Saturnino *et al.*, 2005
		Shell		3.7-4.1		28.8-32.0	Rivera Lorca & Ku Vera, 1997
				4.3-4.5	0.7-1.4	83.9-89.4	Makkar & Becker, 1997
				7.80		53.52	Mattana Saturnino *et al.*, 2005
		Kernel		24.6	47.3	10.1	Akintayo, 2004
				22.2-27.2	56.8-58.4	22.2-27.2	Makkar & Becker, 1997
				26.0	53.0	5.0	Makkar *et al.*, 1997
			57.4-62.0	14.1-19.6		1.9-3.0	Rivera Lorca & Ku Vera, 1997
					56.88	4.33	Mattana Saturnino *et al.*, 2005
			74.0				Shah *et al.*, 2005
Plant oil							
Seed cake				56.4-63.8	1.0-1.5	8.1-9.1	Makkar & Becker, 1997

Successful detoxification processes included moist heating at 121 °C for 25 minutes to inactivation of trypsin inhibitors, slightly decreasing phytate levels by irradiation at 10 kGy, and reducing saponin contents by ethanol extraction and irradiation (Martínez Herrera *et al.*, 2006). Extraction with ethanol, followed by treatment with 0.07% $NaHCO_3$ decreased lectin activity considerably. This treatment also decreased the phorbol ester content by 97.9% (Martínez Herrera *et al.*, 2006). Phorbol esters of *J. curcas* decompose quickly as they are very sensitive to elevated temperatures, light and atmospheric oxygen (NIH, 2007); they decompose completely within 6 days (Rug & Ruppel, 2000).

2.11 Superior or elite *J. curcas* accessions

It is unverified that superior or elite accessions of *J. curcas* exist, or that well performing *J. curcas* provenances will perform successfully when moved to other locations with different environmental circumstances (soil, climate) and management. *J. curcas* still is a wild species, and genetic identification of provenances and testing them in different locations and conditions should be priority research for the coming years.

Provenance trials with local *J. curcas* accessions are reported for India (Ginwal *et al.*, 2004; Lal *et al.*, 2004; Basha & Sujatha, 2007; Kaushik *et al.*, 2007; Patolia *et al.*, 2007b), and for various accessions, mainly from Africa (Makkar *et al.*, 1997). They reveal that the genetic base of *J. curcas* provenances from India is quite small (Basha & Sujatha, 2007), that significant differences in plant morphological aspects (plant height, leaf area index, stem girth, number of primary-secondary-tertiary branches) and yield contributing factors (fruits plant^{-1}, seeds plant^{-1}, seed weight and oil%) could be distinguished between provenances (Patolia *et al.*, 2007b).

3. Conclusions

This study 'Claims and Facts on *Jatropha curcas* L.' has revealed that the wild species *J. curcas* has great potential and value to be exploited in its natural environment of semiarid and arid conditions in the tropics. The traditional and successful application of *J. curcas* includes functions like soil water conservation, soil reclamation, erosion control, living fences, firewood, green manure, lightning fuel and local use in soap production, insecticide and medicinal application at modest scale. For these applications, the majority of claims stated in section 2 (page 5) can be sustained by literature findings.

However, as soon as *J. curcas* is related to *high oil yield production*, a claim which in itself is not backed up by any scientific findings so far, (especially not at large scale), a risk warning should be given about the validity of these claims. Especially the claims of low nutrient requirements (soil fertility), low water use, low labour inputs, the non existence of competition with food production, and tolerance to pests and diseases are definitely not true in combination with high oil yield production. In the sections 3.1 to 3.4, the main conclusions drawn from facts in relation to these claims are summarized.

Note: It has become clear that there is need for an analytical framework that could be applied to *J. curcas* tillage systems and *J. curcas* applications. Such an analytical framework should provide a clear scope of the *J. curcas* potential in different environments and social settings. In Chapter 4 (page 29 and further), elements for such a framework are presented, which could help to understand the impact of *J. curcas* for different types of applications, and at different production scales.

3.1 Scientific base to support claims

- The claims hat have led to the popularity of *J. curcas* as an oil producing crop, are based on the incorrect combination of positive characteristics, which are not necessarily present in all *J. curcas* accessions, and have certainly not been proven beyond doubt in combination with its oil production.
- A major constraint for the extended use of *J. curcas* seems to be the lack of knowledge on its potential yield under sub-optimal and marginal conditions. This makes it difficult to predict yields for future plantations under sub-optimal growth conditions, the conditions where *J. curcas* is especially supposed to prove its value.
- The productivity of *J. curcas* envisages a severe lack of quantitative data, and more specific, a lack of description of conditions under which data were collected.
- It should be noted that the definition of 'waste land' as a possible place for *J. curcas* growth and production is a rather ambiguous term, and should not be confused with the term 'marginal soils' or 'marginal lands', which indicate areas with sub-optimal environmental (climate, soil) growth conditions.
- All studies that express seed yield (or oil yield) per tree (and not per area base, e.g. per hectare) should be carefully analyzed and valued, to avoid misinterpretation and the negligence of competition effects for radiation, water and fertility, especially in the situation of plantations and in intercropping systems.
- For reported yield values it is not often clear if values apply to fresh or dry weight (and how dry weight is expressed), and if the whole fruit, the complete seed with its kernel, or the kernel alone is meant.
- There is a need for proper growth analyses for *J. curcas* tillage systems, revealing the distribution of dry matter to roots, stems, leaves, fruits and seeds under different circumstances. Especially more knowledge on leaf area index development is needed for calculating radiation interception and transpiration requirements.

3.2 Production areas and yield

- *J. curcas* can be well established on marginal soils and can reach reasonable production, if proper care is given to boost plant growth in the initial growing phases and to maintain production in subsequent years.
- Recently published low production figures mostly apply to young *J. curcas* plantations of 1-2 years old. Currently observed yields range from 0.6 to 4.1 t seed ha^{-1}.
- Reliable predictions of *J. curcas* productivity are largely absent, but are required to make responsible decisions on investments.
- Based on plant physiological variables and depending on growth conditions, such as radiation, water, nutrient availability and the absence of plagues and diseases, and assuming a dry matter distribution of 25% wood/branches, 25% leaves and 50% fruits (30% fruit coat, 70% seed), maximum yields of 7.8 t seed ha^{-1} are projected for mature *J. curcas* stands, An assumed seed oil content of 35% would result in 539-2,720 kg extractable oil ha^{-1} y^{-1}. An extraction efficiency of 75% would then lead to 404-2,040 kg oil, or (assuming an oil density of 0.92 kg litre^{-1}) about 439-2,217 litre oil ha^{-1}.
- In the above example, maximum Harvest Indices (HI, based on dry matter production) for various yield components are HI_{SEED}≈0.35 kg kg^{-1}, $HI_{OILWEIGHT}$≈0.09 kg kg^{-1} and $HI_{OILVOLUME}$≈0.10 litre kg^{-1}.
- The dry matter distribution ratio between fruit coat and seeds might be good selection criteria for increasing seed yield, as well finding *J. curcas* accessions that assign more dry matter to fruits instead of stems and leaves.
- Since the oil content seems not to be related with the seed yield, this variability may be a good criteria for selection.
- To estimate water use, water use efficiency and determine actual evapotranspiration (AET) over potential evapotranspiration (PET) (and the growth reduction factor AET/PET), there is a need for quick and easy assessment of leaf area index (LAI, m^{2} leaf m^{-2} soil) in *J. curcas* stands.

3.3 Toxicity and exploitation of by-products

- The toxicity of *J. curcas* is based on several components (phorbol esters, curcains, trypsin inhibitors and others) that are present in considerable amounts in all plant components (including the oil), which make complete detoxification a complicated process.
- Since the detoxification of *J. curcas* organic material is such a complicated process, it has –so far- only been successful at laboratory scale, and seems not to be suitable for small scale and local application.
- Like other *J. curcas* plant components, the seed cake is toxic and the prospect for successful penetration of the feed market with a detoxified product seems small.
- The seed cake (either as remainder of the pressing process, or as a complete meal) is nutrient rich and therefore very suitable as fertilizer.
- Phorbol esters of *J. curcas* decompose quickly as they are very sensitive to elevated temperatures, light and atmospheric oxygen (NIH, 2007); they decompose completely within 6 days (Rug & Ruppel, 2000).
- To maintain *J. curcas* production at a sustainable level, it is important to take notion of the huge amount of nutrients that are removed from the soil if *J. curcas* by-products are exploited for additional uses, including the bio-refinery concept.

3.4 Socio-economic aspects

- It is unverified that *J. curcas* oil production requires minimum amounts of labour input. The claim that it would be an excellent choice in areas that have low labour capacity should therefore be strongly defied.
- Continuous flowering results in a sequence of reproductive development stages on the same branch, from mature fruits at the base, to green fruits in the middle, and flowers at the top of the branch. This is problematic for mechanized harvesting.

4. The sustainable livelihoods approach (SLA) for small scale farmers

4.1 Introduction

It has become clear that there is need for an analytical framework that could be applied to analyze *J. curcas* tillage systems and other *J. curcas* applications. Such an analytical framework should provide a clear scope of *J. curcas* potential in different environmental and social settings.
In order to assess the usefulness of *J. curcas* for different applications and in these different settings, with the aim to improve the lives of poor people in marginal areas, it is important to have this analytical framework that allows comprehending the drivers for success and evaluating effects on various aspects of small scale farmers. This section describes the Sustainable Livelihood Approach as such an analytical framework applied for different *J. curcas* systems.

4.2 Analytical framework

The sustainable livelihoods approach draws on a framework developed in the late 1990s. This framework brings together conceptual insights based on research conducted in rural and urban locations since the late 1980s – in a way, it can be perceived that the SLA summarises several years of thinking about poverty and vulnerability (Chambers, 1987; Chambers & Conway, 1992; Sen, 1997; Moser, 1998; Bebbington, 1999).

Here a sustainable livelihood is defined as:
'*comprising the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks, and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base*'
(Carney, 1998).

The central concept of the SLA is that individuals and households rely on a 'basket' of assets which form the basis of their activities (or livelihood strategies). The following 5 assets are distinguished (Figure 16):

- **Human assets**; such as health, skills, religion and education.
- **Physical assets**; such as infrastructure, housing, etc.
- **Social assets**; such as participation in social networks and political voice to influence decision-making – in other words, representation and influence; often seen as the most critical asset, as it mediates access to the other assets.
- **Financial assets**; such as earnings, savings, access to credit, remittances, etc).
- **Natural assets;** such as natural resources, both private – land – and common environmental resources.

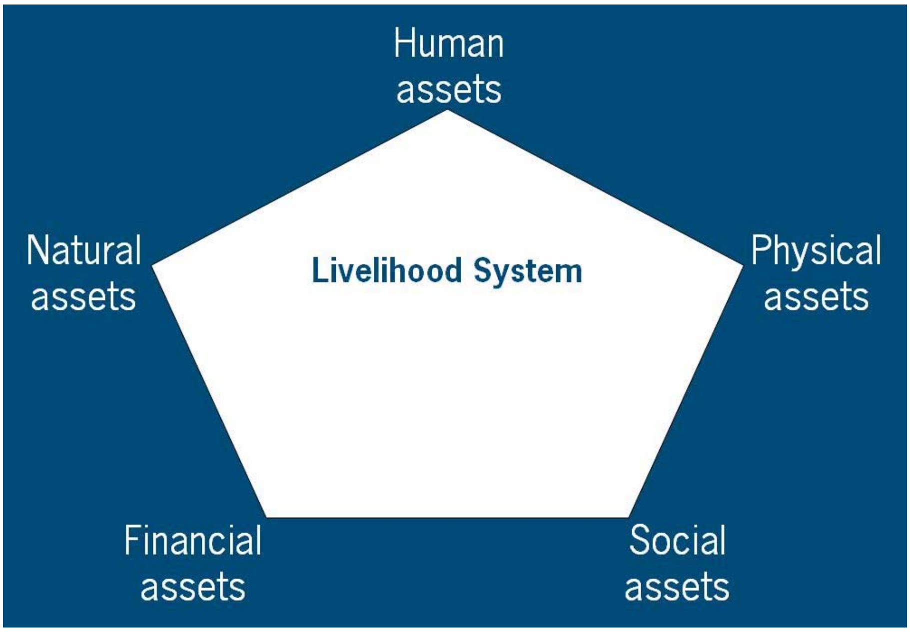

Figure 16. The 5 corner stones of a Livelihood System.

Social capital in the sense of voice and representation to influence policy is what poor and marginalised groups often lack. Strengthening civil society and participatory democracy are closely related to increasing their social capital.

Livelihood strategies are a rational response to the external context, and are developed on the basis of the available assets. Increasing the asset-base (and therefore increasing the capacity to respond to external stresses and shocks and improve livelihoods) is the result of accumulation strategies. This, in turn, means that in order to identify priorities and feasibility for action it is critical to examine the asset-base of different individuals, households and communities. Food security, measured in terms of the nutritional status of the livelihood members, is viewed as one of the outcomes of livelihood strategies.

When the asset-base is low and external shocks and stresses too strong, livelihood strategies can be defined as ‘survival’ or ‘coping’ strategies: people still try and make the best possible use of their assets, but are forced to deplete them in the process. A typical example of this is when small-scale farmers are forced to sell seed or livestock because of declines in production or in farm-gate prices; or when poor urban-based households must take children out of school because they need whatever income they can generate.

The external context is defined in the framework as the ‘vulnerability context’. Vulnerability is important: it describes the fact that many people are not set in static positions, but actually move in and out of poverty at different times in their lives.

Depending on their personal circumstances (for example, loss of income due to illness, loss of support from family and community, perhaps through divorce or widowhood, etc.), the circumstances of their household (often a large number of dependants compared to active members – this may be part of the natural life cycle of the household, or due to illness and death of the ‘productive’ age group, as is often the case with HIV/AIDS; etc.), external sudden shocks (natural disasters, conflicts, etc) and longer-term trends (decline in natural resources in relation to population density, policy changes in relation to agricultural markets, public services, etc.).

4.3 Key message

The key message of the SLA is that people manage risk and cope with shocks and hazards (described in the vulnerability context) actively and in a variety of ways. The main role for policy is therefore to raise the asset status of poor individuals and households, and in this way strengthen their own inventive solutions rather than substitute for, block or undermine them. Policies and institutions can therefore play a critical role in enabling and encouraging strategies that improve livelihoods. But at the same time, many policies and institutions can disable and discourage such improvement. Understanding the role of policies at the local, national and international levels is essential to promote change, as is supporting the development of accountable and competent local institutions.

4.4 Examples

To illustrate the application of the Sustainable Livelihoods Approach, 2 examples for *J. curcas* application are presented. The first example comprises the use of *J. curcas* production as merchandize commodity for economy reasons in Brazil, and the second example is the use of *J. curcas* production as a catalyst for rural development, with Tanzania and Uganda in East Africa as a special case (Table 6).

Table 6. Examples of J. curcas *application as merchandize commodity and as catalyst for rural development.*

Approach	Top down support	Bottom up impulse
Role of bio-fuel	Merchandize	Catalyst
Application	Economy	Rural development
Use/Market	Regional/National	Local
Examples	Brazil: Jatropha/Castor	East Africa: Jatropha/Sunflower

4.4.1 Top down support in Brazil

The government of Brazil has committed itself to promote biodiesel production through political intervention (Law 11.116/05, Decrete 5.297/04). This action can be described as 'Top down support' of farmers with the available political tools. To promote biodiesel production, farmers' families may expect tax relief, easy import of technical equipment, minimum export regulations, low Brazilian interest rate and interest relief, easy customs handling, technical assistance, use of harbour facilities and easy permits. In Table 7 it is shown that specifications per region, crop type and producer type influence the eventual tax reduction rate.

Table 7. Federal contribution for biodiesel production in Brazil by tax reduction applied to different situations (Law 11.116/05, Decrete 5.297/04).

Criteria	Situation 1	Situation 2	Situation 3	Situation 4
Region	N/NE +semi-arid	Any	N/NE +semi-arid	Any
Crop	Castor/Palm	Any	Castor/Palm	Any
Producer	Family	Family	Company	Any
Tax (R$/m3)	0.00	70.03	151.50	218.00
Reduction	100%	68%	31%	0%

4.4.2 Bottom up impulse in East Africa

Demand for edible oils will continue to increase in the East African Common Market (EAC - Uganda, Kenya and Tanzania). Currently most of the edible oil is imported as palm-oil, but there is large potential to increase the domestic/regional production of edible oil. Over the past decade, small-scale entrepreneurs have engaged in local production and processing, in particular of sunflower and to a lesser extent groundnut, sesame seeds and other. In Uganda, production volumes of sunflower are under pressure and in Kenya and Tanzania areas and yields are decreasing, also because of unfavourable policies and other conditions.

Bio-energy from oil-crops could become a substitute for energy import addressing the chronic energy shortage in the EAC. Especially locally, where import and transport costs are high, bio-energy can be a preferable alternative, more so when produced from non-edible oil crops. The production of bio-fuels for local use could support mechanisation processes as a kick-start for other commercial activities and value-addition to agricultural food chains. Farmers use manual RAM-presses for pressing sunflower, which could be mechanized by bio-diesel produced from crops like *J. curcas*, a plant species that could be integrated in farming systems, as it is part of hedges.

Currently middlemen make windfall profits as they purchase sunflower seeds directly after the harvest because medium processors do not have sufficient capital to purchase all seeds. Affordable loans to these processors might alter the flow of commodities and money. The lack of energy limits the capacity of small processors and farmer groups to increase their production efficiency and quality which shortcoming could be addressed by the local production of bio-energy. Also, rather unexpected interventions might completely alter the game. Concessions given to multinational enterprise operating in Kenya and Tanzania to produce palm oil in Uganda completely altered the priorities and strategies of actors.

Due to these complex interactions and the rapidly changing chain dynamics this vibrant sector is beset with a range of shortcomings that prevent it from catalysing the transformation from subsistence to commercial farmers, and to create opportunities for both poor and rich to reap the fruits of the growing demands for oilseeds in order to reduce poverty and hunger.

4.5 Results

The 5 corner stones from Figure 16 have been assessed for *J. curcas* by a recent study in Tanzania (Sila Matui, 2006), which is applicable for the Uganda situation as well. Some of these results are incorporated in the descriptions below, and in Table 8 and Table 9.

Human assets

Farmers will develop skills and have new labour opportunities in *J. curcas* tillage systems. As a local energy source, with *J. curcas* seeds and oil to cook and to light at night, children in households will be able to read and do their homework at night. Further reading and knowledge exchange is enhanced by transportation opportunities to other villages. Agriculture activities may be mechanized, which reduces the manual labour pressure. Toxicity from *J. curcas* components may be a health thread. Increased nutrition by higher quality of local produce, as it may be processed locally.

Physical assets

Electricity and power will be available, as well as oil presses, pumps, shops and transportation means. Oil storage capacity or warehouses may be built. A processing industry with infrastructure and transportation will develop.

Social assets

Labour increase for men, women and children in traditional farming systems and application in living fences.
J. curcas is also used as a grave stone. In places like Mali and Tanzania, *J. curcas* oil is being used by women to make soap, hence increasing the income of women from the sales of the soap. Household members will be able to market *J. curcas* produce i.e. soap, seeds. Community farming may be an option, with possible knowledge exchange, and awareness of economies. Independency of fossil fuels for transportation may enhance a sense of freedom.

Financial assets

Selling *J. curcas* seed and oil and working in *J. curcas* plantations will provide income and cash flow. Mechanized processing of raw produce will increase farm gate prices for agricultural products. Tax relief for producing biofuels and investment opportunities for *J. curcas* growers will be in place. Market entrance is enabled.

Natural assets

J. curcas may reclaim marginal lands, may improve the soil by reducing wind and soil erosion and incorporating organic mater into the soil. In a monoculture, *J. curcas* may lead to soil exhaustion if not produced in a sustainable way and if by-products or bio-refinery products lead to nutrient removal. Certified production methods may be possible. Possibilities for CO_2 neutral transportation, less damaging exhaust gasses.

Table 8. Top down support of biodiesel production in Brazil.

Human	Physical	Social	Financial	Natural
• Increased skills and education	• Processing industry	• Grouping not required (market prices dominate situation)	• Tax relief	• Reclaim marginal land
• Bargaining skills	• Infrastructure	• Labour increase (gender)	• Investment opportunities	• Certified production methods
• Labour opportunities	• Transportation	• Market access	• Cash flow	• CO_2 neutral
	• Oil storage capacity		• Market entrance	• Exhaust less severe

Table 9. Bottom up impulse of local J. curcas *production in East Africa (Tanzania and Uganda).*

Human	Physical	Social	Financial	Natural
• Increased skills and education	• Electricity/Power/ Light	• Community farming	• Local value addition (processing)	• Increased resource use efficiency
• Raised awareness	• Oil presses	• Knowledge exchange	• Increased income (to be invested?)	• Sustainable production
• Own responsibility	• Pumps	• Independency		• CO_2 neutral;
• Increased nutrition by local quality increase	• Shops	• Gravestones		• Exhaust less severe
• Labour opportunities	• Oil storage capacity	• Family market access		
• Reduced manual labour	• Transportation			
• Toxicity of components				

4.6 Conclusions

- Development strategy depends on local conditions, opportunities and market setting.
- Combination of both bottom up impulse and external policy support might give promising development opportunities.
- Effects can be quantified through the 5 pillars of the Sustainable Livelihoods Approach.

5. Acknowledgements

This report is a publication of the '*Jatropha curcas* evaluation, breeding and propagation programme', running from 2006-2010 and financed by Stichting Het Groene Woudt (SHGW), the Netherlands. We are most grateful for their support and belief that a sound scientific base is needed for the successful exploitation of the potentials of *J. curcas* as a bioenergy crop for traditional small scale farming and large scale plantations.

Furthermore, we are grateful to the people at Fuels from Agriculture in Communal Technology (FACT; www.fact-fuels.org), the Netherlands, who have provided full cooperation and opening of their archives with regards to their *Jatropha curcas* resources. As the organizers of the 'Expert seminar on *Jatropha curcas* L. Agronomic and genetics' in Wageningen from 26-28 March 2007, they have succeeded in bringing global knowledge and experience on *J. curcas* to Wageningen, where it was shared among colleagues. Many of the contributions of that expert seminar have been a valuable resource for this report.

Invitation for Participation in the Global *Jatropha curcas* evaluation Programme (2006-2010)

On behalf of the Global *Jatropha curcas* evaluation Programme (JEP) that we coordinate at Wageningen University and Research centre - Plant Research International (See Appendix I), I would like to draw your attention to the posibility to participate in this programme and to compare your *J. curcas* collection with others all over the world.

As you may understand, our programme will only succeed if more *J. curcas* collections are integrated in the analyses. Therefore we are looking for more contacts in more countries, for more environmental circumstances (precipitation, soil fertility), different *J. curcas* management situations and more *J. curcas* collections to be included in our evaluation programme, which will become publicly available.

Your leaf material will be genetically analyzed free of charge, thereby identifying to which 'group' of *J. curcas* accessions your material belongs to. Then you can see what may be expected (in terms of crop development, crop production and oil content) from your *J. curcas* accession, if you compare it to other accessions from the same group, but grown under different circumstances. You may be able to adapt your management to obtain better results, or seek contact with people dealing with a specific *J. curcas* accession to your interest.

So, if you have not already done so, please visit www.jatropha.wur.nl and find out how you can participate with your collection. Actually, it's quite easy: you leave your contact details on the website and indicate how many *J. curcas* accessions (*J. curcas* plant material from the same origin and managed in the same way) you have access to, and we will send out the Material Aquisition Agreement (Appendix II), the Plant Material Collection Kits with clear sampling instructions (Appendix III), and the Questionnaires (Appendix IV) concordingly.

Since January 2007, we have sent out kits for more than 350 *J. curcas* accessions all over the world (28 countries), each accompanied by a Material Aquisition Agreement (See Appendix II), clearly stating that we DO NOT claim ownership of your *J. curcas* germplasm (it's your material after all!) and to explain our scientific interest that would be benificial for all people working with *J. curcas*. Project results will be disseminated to all registered contacts.

So again, please consider participation in the Global *Jatropha curcas* Evaluation Programme and if you can not participate yourself, forward this message to any of your contacts that may be interested!

Sincerely yours,

Dr ir Raymond Jongschaap, Wageningen University and Research centre, Plant Research International

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Appendix I.

Project flyer Global *J. curcas* Evaluation Programme (2006-2010)

General project flyer

Jatropha curcas evaluation, breeding and propagation programme (JEP)

www.jatropha.wur.nl

The *Jatropha curcas* evaluation, breeding and propagation programme (JEP) is carried out by Wageningen University and Research centre, Plant Research International, the Netherlands.

Rationale

Jatropha curcas is a multi-purpose tree, growing naturally in countries of the equatorial Americas, whereas it has been spread to other tropical countries as well. Jatropha seeds are rich in oil and when extracted, pure plant oil can be used directly or as biodiesel in engines.
For this reason, *Jatropha curcas* is an attractive crop and it is being introduced rapidly in various rural programmes, as it may contribute to rural development by income generation and increasing the efficiency of rural and agricultural processes.
However, *Jatropha curcas* production varies greatly and profitable claims are made without well-founded proof nor with reliable sources of information. Being an uncultivated wild-species, it is not known what the environmental and the genetic influence is on oilseed production. This information is critical to increase the chances of *Jatropha curcas* development programs with appropriate knowledge on how to cultivate what line of *Jatropha curcas* under which environmental and agronomic conditions.

Objective

The objective of this programme is to minimize risks involved in the introduction of *Jatropha curcas* as oil producing crop in developing countries, where it concerns productivity in relation to environmental settings and crop management.

Approach

Cultivated and wild-lines of *Jatropha curcas* are collected globally with associated 'passport data'. The required data include information on productivity, oil contents, growth conditions, agronomic practices, propagation methods and sensitivity to pests and diseases.
Living gene pools are maintained in their originating countries. Young leaf and seed material is sampled from natural and commercial *Jatropha curcas* stands. Analysis of these data allows distinguishing more or less promising lines in relation to their growing environments. Finger-printing of the collected material and some preliminary research using biotechnological approaches will prepare for future breeding and propagation programmes. Cross-breeding and agronomic experiments will be initiated with selected lines.

Programme duration and reach

This first phase of the *Jatropha curcas* evaluation, breeding and propagation programme runs from 2006 until 2010.
The programme is embedded in a larger framework of stakeholders dealing with all aspects of renewable energy and is not restricted to agronomic production goals only.

Participation

The *Jatropha curcas* evaluation, breeding and propagation programme is open for participation. You can supply information on your *Jatropha curcas* collection through a questionnaire and by supplying young leaf material that will be integrated in the various analyses. We will provide feed back on the analysis results of your *Jatropha curcas* collection and update you on the project progress and on special events, such as stakeholder workshops and new initiatives that you may want to participate in. Overall project findings will be made publicly available.

Participate with your *Jatropha curcas* collection: contribute and benefit with this world wide evaluation programme!
www.jatropha.wur.nl

To participate in the evaluation programme, you may contact the project team for a leaf material collection kit and for instructions on filling out the questionnaire. Your information is crucial for a well-founded global analysis of *Jatropha curcas*.

Contact information

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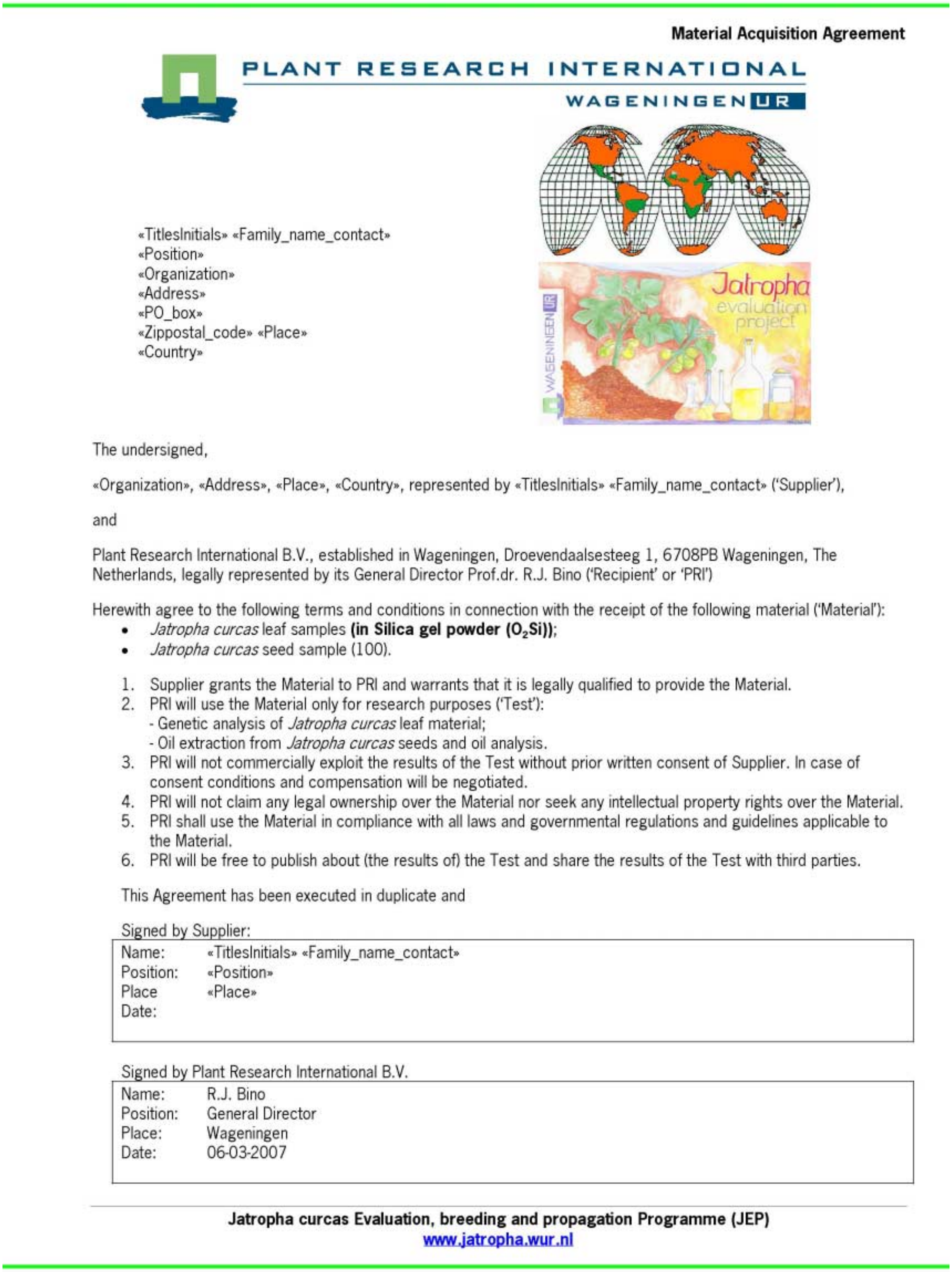
W www.jatropha.wur.nl

Appendix II.

Material Acquisition Agreement



Material Acquisition Agreement

PLANT RESEARCH INTERNATIONAL
WAGENINGEN UR

«TitlesInitials» «Family_name_contact»
«Position»
«Organization»
«Address»
«PO_box»
«Zippostal_code» «Place»
«Country»

The undersigned,

«Organization», «Address», «Place», «Country», represented by «TitlesInitials» «Family_name_contact» ('Supplier'),

and

Plant Research International B.V., established in Wageningen, Droevendaalsesteeg 1, 6708PB Wageningen, The Netherlands, legally represented by its General Director Prof.dr. R.J. Bino ('Recipient' or 'PRI')

Herewith agree to the following terms and conditions in connection with the receipt of the following material ('Material'):

- *Jatropha curcas* leaf samples **(in Silica gel powder (O_2Si))**;
- *Jatropha curcas* seed sample (100).

1. Supplier grants the Material to PRI and warrants that it is legally qualified to provide the Material.
2. PRI will use the Material only for research purposes ('Test'):
   - Genetic analysis of *Jatropha curcas* leaf material;
   - Oil extraction from *Jatropha curcas* seeds and oil analysis.
3. PRI will not commercially exploit the results of the Test without prior written consent of Supplier. In case of consent conditions and compensation will be negotiated.
4. PRI will not claim any legal ownership over the Material nor seek any intellectual property rights over the Material.
5. PRI shall use the Material in compliance with all laws and governmental regulations and guidelines applicable to the Material.
6. PRI will be free to publish about (the results of) the Test and share the results of the Test with third parties.

This Agreement has been executed in duplicate and

Signed by Supplier:

Name: «TitlesInitials» «Family_name_contact»
Position: «Position»
Place «Place»
Date:

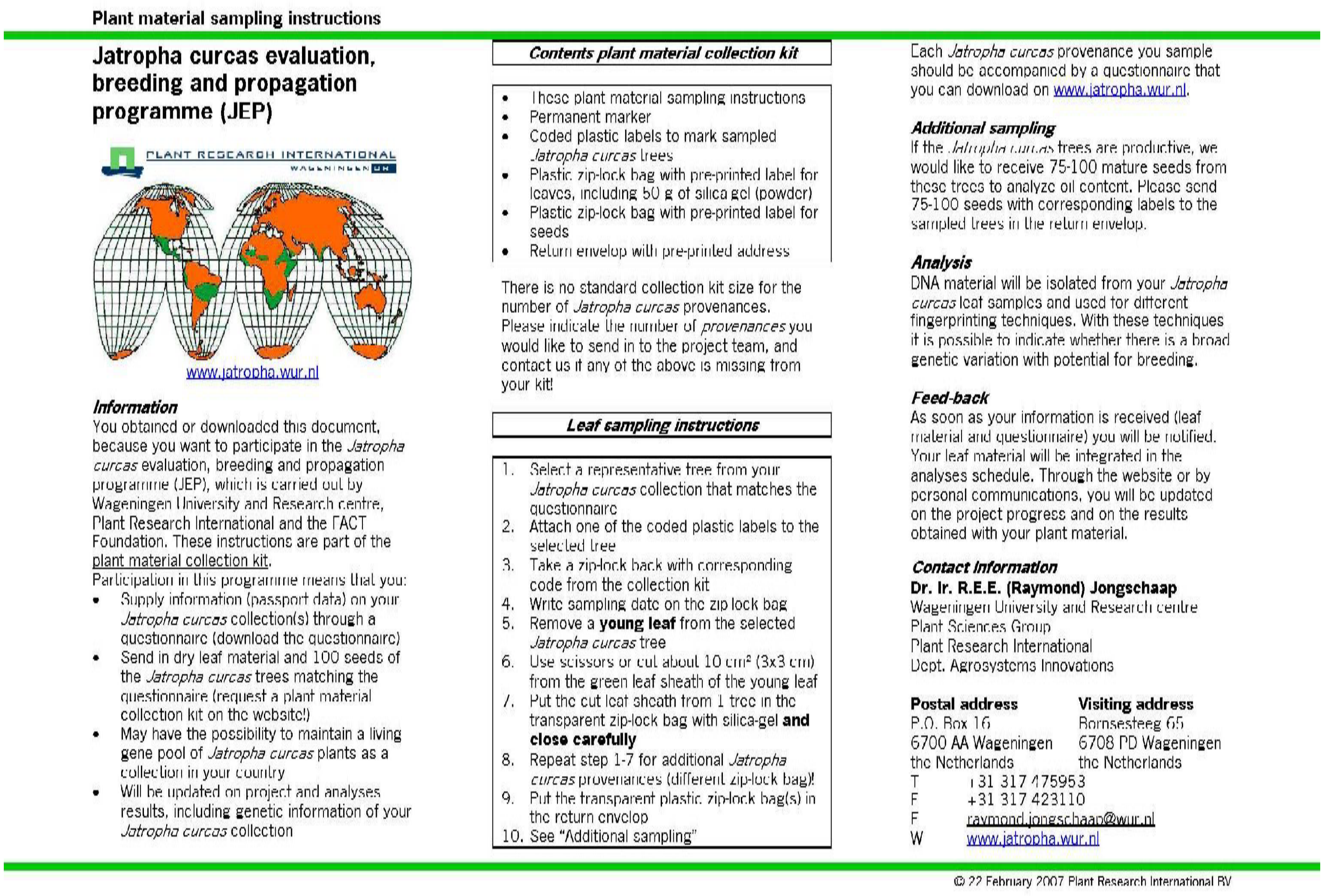
Signed by Plant Research International B.V.

Name: R.J. Bino
Position: General Director
Place: Wageningen
Date: 06-03-2007

Jatropha curcas Evaluation, breeding and propagation Programme (JEP)
www.jatropha.wur.nl

Appendix III.

Plant Material Sampling Instructions



Plant material sampling instructions

Jatropha curcas evaluation, breeding and propagation programme (JEP)

www.jatropha.wur.nl

Information

You obtained or downloaded this document, because you want to participate in the *Jatropha curcas* evaluation, breeding and propagation programme (JEP), which is carried out by Wageningen University and Research centre, Plant Research International and the FACT Foundation. These instructions are part of the plant material collection kit.

Participation in this programme means that you:

- Supply information (passport data) on your *Jatropha curcas* collection(s) through a questionnaire (download the questionnaire)
- Send in dry leaf material and 100 seeds of the *Jatropha curcas* trees matching the questionnaire (request a plant material collection kit on the website!)
- May have the possibility to maintain a living gene pool of *Jatropha curcas* plants as a collection in your country
- Will be updated on project and analyses results, including genetic information of your *Jatropha curcas* collection

Contents plant material collection kit

- These plant material sampling instructions
- Permanent marker
- Coded plastic labels to mark sampled *Jatropha curcas* trees
- Plastic zip-lock bag with pre-printed label for leaves, including 50 g of silica gel (powder)
- Plastic zip-lock bag with pre-printed label for seeds
- Return envelop with pre-printed address

There is no standard collection kit size for the number of *Jatropha curcas* provenances. Please indicate the number of *provenances* you would like to send in to the project team, and contact us if any of the above is missing from your kit!

Leaf sampling instructions

1. Select a representative tree from your *Jatropha curcas* collection that matches the questionnaire
2. Attach one of the coded plastic labels to the selected tree
3. Take a zip-lock back with corresponding code from the collection kit
4. Write sampling date on the zip lock bag
5. Remove a **young leaf** from the selected *Jatropha curcas* tree
6. Use scissors or cut about 10 cm^2 (3x3 cm) from the green leaf sheath of the young leaf
7. Put the cut leaf sheath from 1 tree in the transparent zip-lock bag with silica-gel **and close carefully**
8. Repeat step 1-7 for additional *Jatropha curcas* provenances (different zip-lock bag)!
9. Put the transparent plastic zip-lock bag(s) in the return envelop
10. See "Additional sampling"

Each *Jatropha curcas* provenance you sample should be accompanied by a questionnaire that you can download on www.jatropha.wur.nl.

Additional sampling

If the *Jatropha curcas* trees are productive, we would like to receive 75-100 mature seeds from these trees to analyze oil content. Please send 75-100 seeds with corresponding labels to the sampled trees in the return envelop.

Analysis

DNA material will be isolated from your *Jatropha curcas* leaf samples and used for different fingerprinting techniques. With these techniques it is possible to indicate whether there is a broad genetic variation with potential for breeding.

Feed-back

As soon as your information is received (leaf material and questionnaire) you will be notified. Your leaf material will be integrated in the analyses schedule. Through the website or by personal communications, you will be updated on the project progress and on the results obtained with your plant material.

Contact Information

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Plant Sciences Group
Plant Research International
Dept. Agrosystems Innovations

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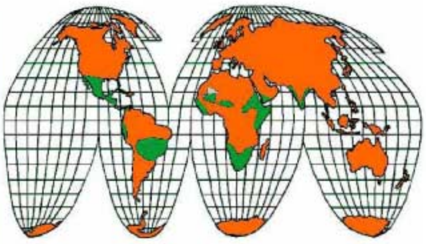
Appendix IV.

Questionnaire

PLANT RESEARCH INTERNATIONAL
WAGENINGEN UR

Fact foundation

JEP
Jatropha curcas evaluation, breeding and propagation programme



www.jatropha.wur.nl

Questionnaire Jatropha curcas

Please provide the data* for a homogeneous *Jatropha curcas* stand, and send in leaf and seed material from the same stand. See www.jatropha.wur.nl for project information.

Please fill in contact information

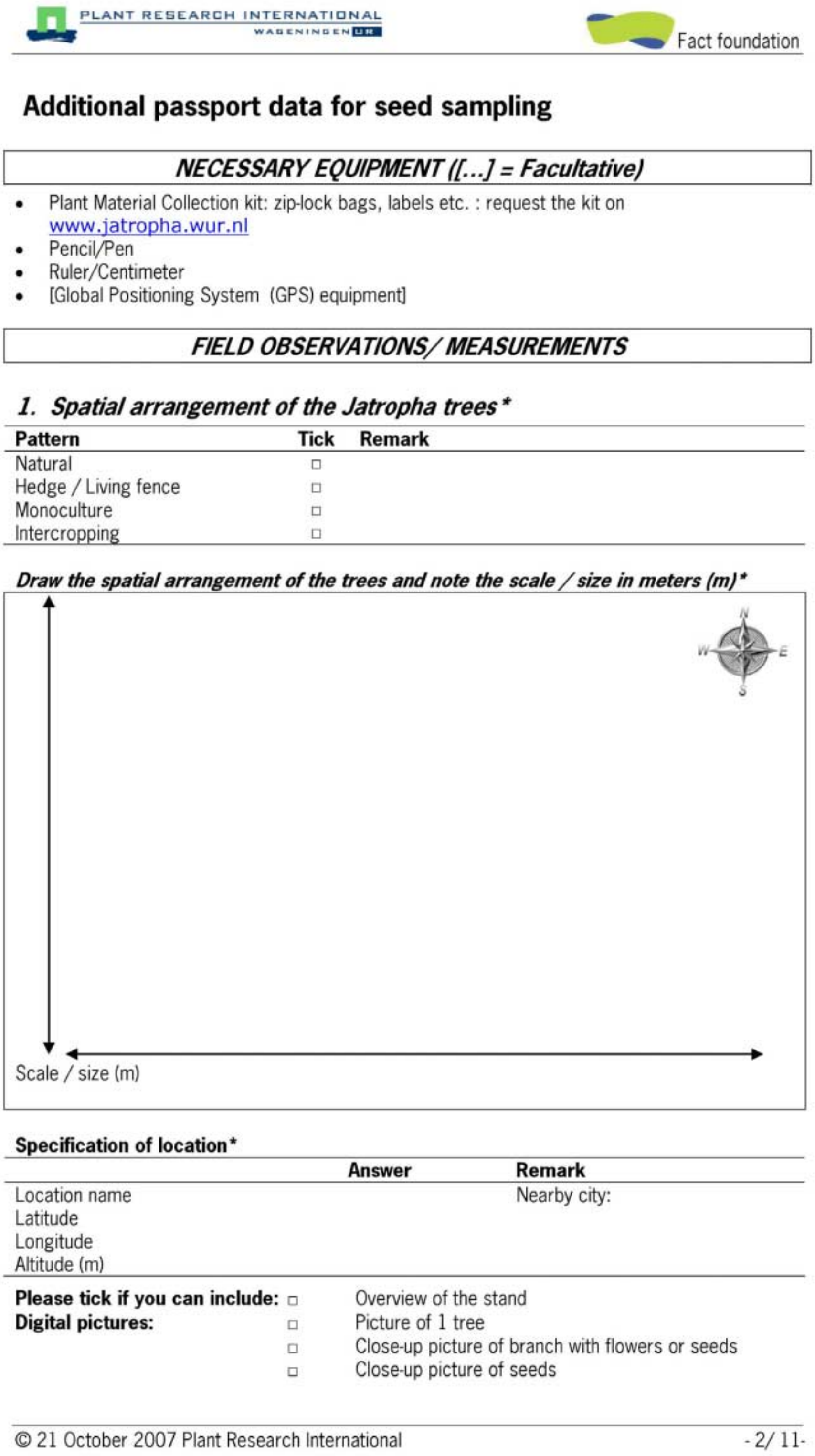
Date			
First Name		Last Name	
Organization			
Address			
Postal code			
City		Country	
Telephone			
Mobile phone			
Fax			
E-mail address 1		E-mail address 2	
Internet address			

Please return to:

Plant Research International BV Mr P.W.J. (Peter) Uithol P.O. Box 16 NL-6700AA Wageningen The Netherlands Email: peter.uithol@wur.nl	Code:

Questions marked with * need to be answered

Answers to all other questions are provisional, but well appreciated!



PLANT RESEARCH INTERNATIONAL
WAGENINGEN UR

Fact foundation

Additional passport data for seed sampling

NECESSARY EQUIPMENT ([…] = Facultative)

- Plant Material Collection kit: zip-lock bags, labels etc. : request the kit on www.jatropha.wur.nl
- Pencil/Pen
- Ruler/Centimeter
- [Global Positioning System (GPS) equipment]

FIELD OBSERVATIONS/ MEASUREMENTS

1. Spatial arrangement of the Jatropha trees*

Pattern	Tick	Remark
Natural	☐	
Hedge / Living fence	☐	
Monoculture	☐	
Intercropping	☐	

Draw the spatial arrangement of the trees and note the scale / size in meters (m)*

Scale / size (m)

Specification of location*

	Answer	Remark
Location name		Nearby city:
Latitude		
Longitude		
Altitude (m)		

Please tick if you can include:
Digital pictures:

☐ Overview of the stand
☐ Picture of 1 tree
☐ Close-up picture of branch with flowers or seeds
☐ Close-up picture of seeds

2. *Field position / size**

	Tick	Answer	Remark
Place of the field	☐	Valley	☐ 0-2° ☐ 2-5° ☐ 5-10° ☐ >10°
	☐	Bottom slope	
	☐	Mid slope	
	☐	Top slope	
	☐	Plateau	
b) Orientation of the slope	☐	North	
	☐	East	
	☐	South	
	☐	West	
c) Size of the field	Length (m)		(or in hectare: ha)
	Width (m)		

3. *Intercropping**

	Answer	Remark
Name(s) of crop(s) associated with Jatropha curcas		
Specific rotation?	☐ Yes ☐ No	Details:
Close up picture of the other crop(s)	☐ Yes ☐ No	

4. *Density of Jatropha trees**

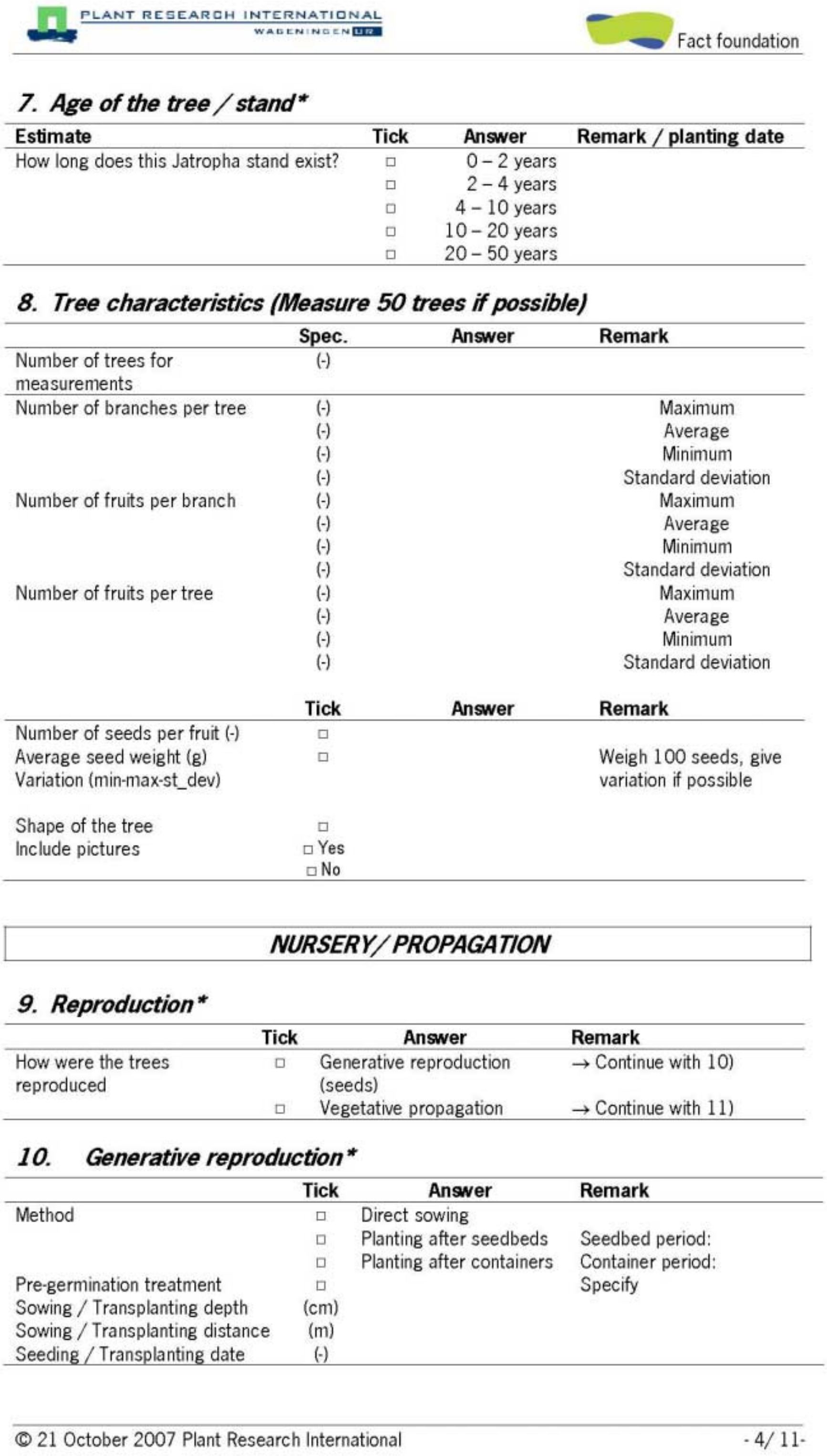
Estimate	Unit	Answer	Remark
a) Number of trees in area of 10 x 10 m	(#)		In case of a mono crop
b) Number of trees along a line of 10 m	(#)		In case of a hedge
c) Single rows / Double rows / Triple rows	(-)		In case of intercropping
d) Number of trees in the field	(-)		
e) Distance between rows	(m)		
f) Distance in row	(m)		

5. *Tree dimensions / stand (m)**

Estimate / Measure	Tick	Answer	Natural / Pruned	Remark
What is the height of the trees	☐	0 – 1 m		
	☐	1 – 2 m		
	☐	3 – 4 m		
	☐	4 – 5 m		
What is the crown width				

6. *Stem diameter of the tree / stand (cm) [measure 50 trees if possible]*

Estimate / Measure	Unit	Answer	Remark
Number of trees used for measurements	(-)		
Diameter at 1 m above the ground	cm		Minimum
	cm		Average
	cm		Maximum
	cm		Standard deviation
Diameter of trunk before branching	cm		



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7. Age of the tree / stand*

Estimate	Tick	Answer	Remark / planting date
How long does this Jatropha stand exist?	☐	0 – 2 years	
	☐	2 – 4 years	
	☐	4 – 10 years	
	☐	10 – 20 years	
	☐	20 – 50 years	

8. Tree characteristics (Measure 50 trees if possible)

	Spec.	Answer	Remark
Number of trees for measurements	(-)		
Number of branches per tree	(-)		Maximum
	(-)		Average
	(-)		Minimum
	(-)		Standard deviation
Number of fruits per branch	(-)		Maximum
	(-)		Average
	(-)		Minimum
	(-)		Standard deviation
Number of fruits per tree	(-)		Maximum
	(-)		Average
	(-)		Minimum
	(-)		Standard deviation

	Tick	Answer	Remark
Number of seeds per fruit (-)	☐		
Average seed weight (g)	☐		Weigh 100 seeds, give variation if possible
Variation (min-max-st_dev)			
Shape of the tree	☐		
Include pictures	☐ Yes ☐ No		

NURSERY/ PROPAGATION

9. Reproduction*

	Tick	Answer	Remark
How were the trees reproduced	☐	Generative reproduction (seeds)	→ Continue with 10)
	☐	Vegetative propagation	→ Continue with 11)

10. Generative reproduction*

	Tick	Answer	Remark
Method	☐	Direct sowing	
	☐	Planting after seedbeds	Seedbed period:
	☐	Planting after containers	Container period:
Pre-germination treatment	☐		Specify
Sowing / Transplanting depth	(cm)		
Sowing / Transplanting distance	(m)		
Seeding / Transplanting date	(-)		

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11. *Vegetative propagation**

	Tick	Answer	Remark
Part of the plant that was used for propagation	☐	Stem cutting	Size (cm) Number of nodes (-)
	☐	Branch cutting	Size (cm) Number of nodes (-)
	☐	Root cutting	Size (cm) Number of nodes (-)
Treatment	☐	Type (hormonal, oth.)	
Planting method	☐	Direct sowing	
	☐	Transplanting after seedbeds	Seedbed period:
	☐	Transplanting after containers	Container period:
Transplanting depth	(cm)		
Transplanting date	(-)		

ADDITIONAL INFORMATION FROM ANALYSIS / INTERVIEWS

12. *Seed characteristics [only if available]*

	Tick	Answer	Remark
Chemical composition	☐		Specify if available
Toxicity	☐		Specify if available
Average seed weight	☐		Weigh 100 seeds
Oil Content (%)	☐		Specify if available
Seed moisture content	☐		
Germination rates	☐		Test 3x 100 seeds
Optimal conditions			Specify conditions
Farmers practice			Specify conditions
Time between measurement - harvest		Drying method:	
Seed measures	☐		
Length	(mm)		Measure 50 seeds
Width	(mm)		Measure 50 seeds
Thickness	(mm)		Measure 50 seeds

13. *Provenance of tree / stand*

	Tick	Answer	Remark
What is the origin of this Jatropha curcas stand (mother material)	☐	Wild habitat	
	☐	Farm / Plantation field	
	☐	Farm / Plantation store	
	☐	Village market	
	☐	Commercial market	
	☐	Institute / Research station	
Were any selection procedures for this Jatropha curcas provenance	☐	Yes	Specify:
	☐	No	
Is there a research station dealing with Jatropha curcas	☐	Yes	Name:
	☐	No	
Date / year/ era of introduction of this variety in the area			
Country of origin as far back in history			
Local name for Jatropha curcas			

14. *Management practices of this Jatropha field [if available]*

	Tick	Answer	Remark
Field preparation	☐	Clearing	What:
	☐	Ploughing	Depth:
	☐	Water conservation methods	What:
	☐	Soil erosion prevention methods	What:
	☐	...	
Fertilization date(s)	(-)		
Fertilization type(s)	(-)		
Fertilization rate(s)	(kg ha^{-1})		
Irrigation date(s)	(-)		
Irrigation type(s)	(-)		
Irrigation rate(s)	(mm ha^{-1})		
Weeding type(s)			
Weeding date(s)			
Pruning type(s)	(-)		
Pruning date(s)	(-)		

15. *Crop development of this Jatropha stand**

	Unit		Answer	Remark
What is the flowering period	(months)			
1st flowering date	(-)			
Last flowering date	(-)			
Time between flowering and harvest	(weeks)			
Dormant period	☐	Yes		When:
	☐	No		
Shed leaves	☐	Yes		When:
	☐	No		
Seasonality of dormancy	date			
	cause	drought / cold / other		
Time needed for regeneration				

16. *Pests and diseases*

	Tick	Answer	Remark				
Did the stand suffer from any pests of diseases	☐ ☐	No Yes:	Type	Type	Type	Type	Type
- include **pictures**			☐	☐	☐	☐	☐
Crop sanitation measure date(s)	(-)						
Crop sanitation measure type(s)	(-)						
- product name / type							
- active ingredient							
- include **pictures**							
Crop sanitation measure rate(s)	…						
- application rate			Of application type				
- application rate			Of active ingredient				

17. *Production**

	Tick	Answer	Remark
Number of harvests per year			Per field with ….. trees Per ha
Harvest date(s)	(-)		
Method of drying of seeds			
Yield (kg seeds ha^{-1}), or	☐		
Yield (kg seeds tree^{-1})	☐		
Yield variation over years			See also next point on "historical records…"
Variation in the field			

18. *Historical records of production of this stand (if available)* *(…)= any other characteristic (fill in)*

Year (-)	Yield (kg ha^{-1})	Oil (%)	Fiber (%)	… ( )	… ( )	Year (Dry/Wet)	Year (Warm/Cold)

19. *Soil fertility (estimations)*

	Tick	Answer	Remark
Soil fertility	☐	Very poor	
	☐	Poor	
	☐	Normal	
	☐	High	
	☐	Very fertile	
Soil organic matter content	(%)		

20. *Soil drainage / Wetness / Irrigation (estimations)*

	Tick	Answer	Remark
Soil drainage	☐	Very poorly drained	
	☐	Poorly drained	
	☐	Normally drained	
	☐	Well drained	
	☐	Very well drained	
Wetness	☐	Dry field	
	☐	Medium Dry field	
	☐	Normal field	
	☐	Medium wet field	
	☐	Wet field	
Irrigation	☐	Yes	How often:
	☐	No	

21. *Soil chemical characteristics (if available)*

	Answer	Remark
Soil pH		
Nutrient content	N-P-K Ca Micro-nutrients	report of soil chemical analysis

22. *Soil physical properties (if available)*

	Tick	Answer	Remark
Soil texture	☐	Clay (%)	
	☐	Loam (%)	
	☐	Sand (%)	
Soil organic matter content	(%)		Or low/medium/high if not available
Soil depth	(m)		

23. *Previous land occupation**

	Tick	Answer	Remark	
What was here before the Jatropha	☐	Natural vegetation	What:	Since:
	☐	Crops	What:	Since:
		Rotation	☐ Yes Crops: ☐ No	
	☐	Nothing	What is the reason for that?	
	☐	Livestock	Which	

24. *Local use of Jatropha**

	Tick	Answer	Remark
Local uses of Jatropha	☐	Medicine	
	☐	Soap	
	☐	Hedge	
	☐	Oil	
Use of the press cake	☐		
Use of residue as fertilizer			

25. *Farmers recommendations/ insights*

Remarks

- What do you consider an attainable yield for this area (kg tree^{-1}) of (kg ha^{-1})
- Were these yields realized?
- Why not, or what is the reason that you think this is possible?
- What do you think is the average yield for this area (kg tree^{-1}) of (kg ha^{-1})
- What has been the lowest yield you have produced (kg tree^{-1}) of (kg ha^{-1})
- What was the reason for that
- What cereal crop is dominant in this area, and what is the maximum attainable yield?

26. *Nearest experimental/ climate station **

	Unit	**Answer**
Name	(-)	
Distance to experimental station	(km)	
Name climate station	(-)	
Distance to climate station	(km)	

27. *Any other remarks*

Remarks

28. *Crop calendar*

Please make cells black when appropriate, and specify if requested and available

Months	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Seasons												
Start principal rains												
Cold months												
Warm months												
Average Temp (°C)												
Wet months												
Dry months												
Precipitation (mm)												
Crop characteristics*												
1st green leaves												
Last green leaves												
Start flowering												
End flowering												
1st mature seeds												
Last mature seeds												
Crop management*												
Planting (normally)												
Pruning												
Harvesting												
Weeding (?)												
Fertilization												
Type												
Rate (kg ha^{-1})												
Irrigation												
Rate (mm)												

Thank you very much for your cooperation!

Please return Questionnaires (by post or electronically) to:

Plant Research International BV

Jatropha curcas Evaluation Program

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