Journal of Earth and Environmental Sciences

Review Article

Tadesse E, Tadesse W, J Earth Environ Sci: JEES-128.
DOI: 10.29011/JEES-128. 100028

Jatrophacurcas: Nature, Uses and Factors Influencing its Management

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Citation: Tadesse E, Tadesse W (2017) Jatropha curcas: Nature, Use and Factors Influencing its Management. J Earth Environ Sci: JEES-128. DOI: 10.29011/JEES-128. 100028

Received Date: 13 July, 2017; **Accepted Date:** 24 August, 2017; **Published Date:** 04 September, 2017

Abstract

Jatropha curcas is a small tree or shrub with a height 3-10 meters and can have a life span of 40-50 years. It has many social, ecological and economic advantages.Regarding its botanical features, it has a straight trunk and glorious branchlets, pale-green leaves, monoecious flowers, a bunch of approximately 10 or more ovoid fruits and have black caster like seeds from which production of oil is possible through processing. Climatically, it is found in the tropics and subtropics. It likes heat but can with stand some amount of frost. Nowadays it has been distributed all over the world especially in the tropical areas including Ethiopia. It has good characteristics which make it suitable for production. For instance, it withstands scarcity of water and soil nutrient stresses.The uses of *J. curcas*are immense andto mention some, folk medicine, reclamation of waste and degraded lands, and income generation through oil production. It can also be mixed with agricultural crops and other tree/ shrubs and hence it has a great value in agroforestry. *J.curcas* can be established both from seeds and through vegetative propagation. It can also be propagated through tissue culture in the laboratory.*J. curcas*needs managements such aswatering, weeding and pruning for good seed and oil production. The oil production from *J. curcas*has its own processes. Some of the processing stages include anaerobic digestion, pyrolysis, gasification, transesterification and combustion. Oil can be extracted from the seeds by heat, solvents or by pressure. *J. curcas*has a potential to be produced in Ethiopia because of good environmental conditions. But there are factors which interrupt good production. These factors include the toxicity of its seeds and leaves, its potential to be weedy, vulnerability to pest and disease attack, lack of good oil extraction methods. Despite its diversified uses, *J. curcas*has not received the necessary consideration and management and hence this review is intendedto show some of the works done about the species and emphasize the uses and future potentials of the species.Generally,it iscrucial to give the required managementssince it has a great potential to be the tree of the future.

Keywords: Distribution; Jatropha curcas;Management; Oil production;Processing; Propagation

Introduction

The name "*Jatropha*" is derived from the Greek words iatros(doctor) and trophe (food)[1]. *Jatropha* is a morphologically diverse genus comprising 160-175 species of trees, shrubs, rhizomatous sub-shrubs and herbs distributed mainly in the seasonally dry tropics[2,3] of these diverse genus, *Jatropha curcas*is a small tree or a large shrub of the family Euphorbiaceae which can attain a height 5-10m [4]. There are also two genotypes of*Jatropha curcas*, a toxic and a non-toxic one. The latter genotypes found in Mexico only[1]. *Jatropha curcas*is a perennial plant with a lifespan of 50 years and more when established from seed and 15 years or less when established from cuttings[3]. It is believed to have originated from Central America, Caribbean or Mexico but has become naturalized in many tropical and subtropical areas such as India, Africa and North America [3,5]. It has been spread as a valuable hedge as well as a medicinal plant to Africa and Asian countries[6].

The tree is deciduous, shedding the leaf in dry season [6]. Flowering occurs during the wetseason and two floweringpeaks are often seen, i.e. during summer and autumn[6].Inpermanently humid regions, flowering occurs throughoutthe year. The inflorescence is axillary paniculatepolychasialcymes[6]. The plant is monoecious and flowers are unisexual;occasionally hermaphrodite flowers occur [6]. With good rainfall conditionsnursery plants may bear fruits after the first rainy season, and directly sown plants after the second rainy season[6].

Jatropha curcas has a smooth gray bark andmostly grows between three and five meters in height, but can also attain a height of up to ten meters under favorable conditions[3].It hasa straight trunk with thick branch lets and green leaveswith a length and width of 6 to 15 cm respectively. Normally, five rootsare formed from seeds; one tap root and 4 lateral rootsand cuttings do not develop a taproot but only the laterals [3].

The plant is resistant to drought and pests, and produces seeds containing oil[7]. The oil from Jatropha curcasis not edible and is traditionally used for manufacturing soap and for medicinal applications[7].Its resistance to drought give it the ability to be cultivated in areas of low rainfall [8].

Jatropha curcas is suitable for quick and efficient domestication compared with other woody species [9]. Therefore, they can be found abundantly in their areas of distribution. At present, there are many varieties of jatrophabeing used to established plantations in Africa and Asia though they are inedible due to their toxicity[10].Despite their abundance and use, none of the *Jatropha*species have been properly domesticated and, as a result, their productivity is variable, and the long-term impact of their large-scale use on soil quality and the environment is not known well[11]. Hence, the objective of this review is to reveal some of the facts written and researches done in some areas about the uses and limitations of the species.

Botanical Features

Figure1: The Jatrophaplant (Source: The Jatropha Handbook.2010. From Cultivation to Application).

Branch and stem

Jatropha curcas L., or physic nut, hasthick glorious branchlets. The tree has a straight trunk with spreading branches, stubby twigs and grey or reddish bark, masked by large white patches[6].

Leaves

It has large green to pale-green leaveswith a length and width of 6 to 15 cm, alternate to sub-opposite, three-to five-lobed with a spiral phyllotaxy.The leaves are arranged alternately[6].

Flowers

The plant is monocious, occasionally hermaphrodite flowers occur.The petiole length ranges between 6-23 mm. The inflorescence is formed in the leaf axial[6].Flowers are formed terminally, individually, with female flowers usually slightly largerand occur in the hot seasons. Ten stamens are arranged in two distinct whorls of five each in a single column in the androecium, and in close proximity to each other. In the gynoecium, the three slender styles are connate to about two-thirds of their length, dilating to massive bifurcate stigma [6]. The rare hermaphrodite flowers can be self-pollinating. The flowers are pollinated by insects especially honey bees. Each inflorescence yields a bunch of approximately 10 or more ovoid fruits.In conditions where continuous growth occurs, an unbalance of pistillate or staminate flower production results in a higher number of female flowers. More number of female flowers is grown by the plant if bee keeping is done along with. More female flowers give more number of fruits and hence seeds[6].

Figure 2: Flowers of *Jatropha curcas* (Source:http://www.stockpodium.com/en/image-photo-7897703/Flower-of-Jatropha-curcas/).

Fruits

Fruits are produced after winter (cold season). It may produce several fruits during the year if soil moisture is good and temperatures are sufficiently high. Each inflorescence yields a bunch of approximately 10 or more ovoid fruits[6].Three, bi-valved cocci is formed after the seeds mature and the fleshy exocarp dries[6].

Figure 3: Fruits of *Jatropha curcas*(Source:http://www.jatrophacurcas-plantations.com/jatropha-curcas-seeds.htm).

Seeds

The seeds of Jatropha curcasare black and nearly18 mm long and 10 mm wide. On average there are 1375 seeds per kg. The seeds become mature when the capsule changes from green to yellow, after two to four months from fertilization. The blackish, thin shelled seeds are oblong and resemble small castor seeds [6].

Figure 4: *Jatropha curcas*seeds (Source: http://faculty.olin.edu/~jtownsend/Renewable%20Fall%202009/docs/Notes%20-%20Jatropha%20Overview.pdf)

Ecological Requirements

Jatrphacurcas is found in the tropical and subtropical climate ranging from tropical very dry to moist through subtropical thorn to wet forest life zones[12]. It grows in altitude of 0-500m, a mean annual temperature of 20-280C and mean rainfall of 300-1000 mm or more. It grows almost anywhere, on gravelly,sandy, poorest stony soils and even in the crevices of rocks [13]. In terms of radiationrequirements, the species is reported to prefer full sunshine [13];however, there are references to better growth under partly shaded growing conditions, where the trees were planted amongst existing bushy vegetation [14].It likes heat, although does well even in lower temperatures and can withstand a light frost. Its water requirement is extremely lowand it can stand long periods of drought by shedding most of its leaves to reduce transpiration loss[15]. The leaves shed during the winter months, forming mulch around the base of the plant, and the organic matterfrom shed leaves enhances earth-worm activity in the soil around the root zone of the plants, which improves the fertility of the soil [15]. The trees prefer a slight to medium slope of ground as opposed to flat ground, but do not tolerate waterlogged soils [14].

The trees have shallow root systems, precluding the use of deep underground stores of water and normally five roots, consisting of one centraland four peripheral, are formed from seedlings[16]. A tap root is not usuallyformed by vegetatively propagated plants [3]. At this stage, there isnothing to indicate that this plant should use any more water than bushy hillside vegetation, and could potentially use significantly less than, forexample, sugarcane or an area of bush encroachment [3].

Distribution

Jatropha curcas is originated from the hot regions of Central and South America and it was introduced by the Portuguese seafarers via the Cape Verde Islands to countries in Africa and Asia [17]. It is widely grown in Mexico,Nicaragua, and Thailand and in parts of India. It is now promoted in Southern Africa, Brazil, Mali and Nepal. It was chosen as one of the prime plant oil species, especially for Brazil, Nepal and the current distributionshows that introduction has been most successful in thedrier regions of the tropics and can grow under a widerange of rainfall regimes from 250 to 1200mmperannum[18].Though native to America, the species is almost pan-tropical now. Today it is cultivated in almost all tropical and subtropicalcountries as protection hedges around gardens and fields, since it is not browsed bycattle[19]. This highly droughtresistant species is adapted to arid and semi-arid conditions. The current distribution shows that introduction has been most successful in the drier regions of the tropics with annual rainfall of 300-1000 mm.

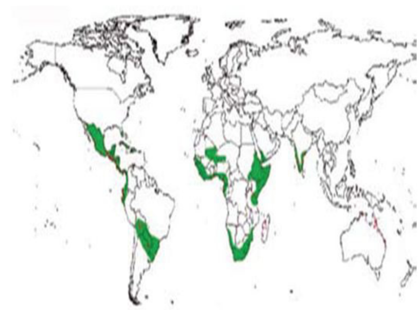

Figure 5: Worldwide Distribution of *Jatropha curcas*[20,21].

Note: The green colored areas are Jatropha curcas ranges of distribution!

In Ethiopia, *Jatropha crucas*growsataltitudes of 450-1300 m and commonly found in Oromiya, Southern People Nations and Nationalities, Tigray, Gambella, BenishangulGumuz and Somali Regional States[22]. It was probably introduced to Ethiopia during the last half of the Nineteenth Century.Studies also indicated that the suitable agro-ecology for Jatropha curcas is the lowland areas of the country (Ethiopia) [22].

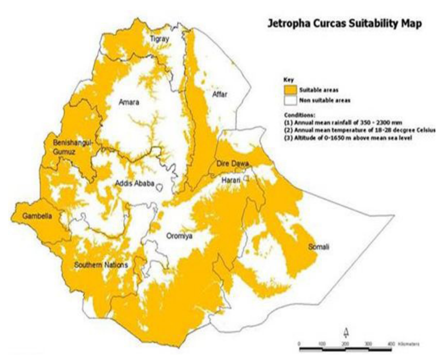

Figure 6: Suitability map for *Jatropha curcas*[22].

Suitabilityof *Jatrophacurcas*for Cultivation and Production

Jatropha curcas L. has a great potential to be used as a favorite agricultural solution for all subtropical and tropical locations becauseit is**:**

- Easy establishment
- Fast growing
- Hardy and requires little can
- Can grow in poor soils and wastelands except flood prone and waterlogged areas
- Not a competitor of any crop rather it increases the yield[23]
- Its leaves and fruitsare toxic and the toxicity is sensed by animals and therefore not foraged on
- Requires only moderate rainfall (approx. 600mm only) and can withstand long periods of drought,
- a permanent, uncomplicated crop that, once established, can last for many decades, and due to its low demand on soil fertility, it is ideal to replant marginal lands to prevent desertification[23].

Uses of *Jatropha curcas*

Jatropha curcas has diversified uses and hence it is considered to be a multi-purpose tree [16].There are studies and publications that have analyzed potential products from, and uses of the leaves, bark, seeds (oil) and roots. The majority of authors are of the opinion that the species has significant potential to increase rural farmers' incomes while providing employment for the poor [12,15,16,24]. As noted by Lele[12], *Jatropha curcas*is deemed to be suitable for the production of bio diesel and related products due to a number of favorable factors.

As a plantation crop *Jatropha curcas*offers the following major advantages:

- Oil yield per hectare is among the highest of all tree-borne oil seeds[16].
- *Jatropha curcas*thrives under plantation conditions but also producesadequate yields on low fertility, marginal, degraded, fallow, waste andotherwise unproductive lands, such as along canals, roads, railway tracks,field borders (as a live hedge), in arid/semi-arid areas and even on alkalinesoils[16].
- The plant is un-demanding in soil type and does not require tillage.
- Being rich in nitrogen, the seed cake is an excellent source of plantnutrients and can be used as a fertilizer.
- Itsseeds are easy to collect, as the plants are not very tall.
- Various parts of the plant have medicinal value. Forinstance, its bark contains tannin[16]
- The flowers attract bees; thus, the plant has honey production potential[16]
- Reclamation of wasteland and degraded land is possible through its plantation;
- It is suitable to tackle the problem of soil erosion;
- *Jatropha curcas* nursery raising,plantation, and oil extraction can be rural based, hencepromoter of rural economy besides ensuring energy security;
- The seed has a very high oil content of approximately 42% (high yielding up to 1000 literofoil per hectare)[16]
- The oil burns with clear smoke-free flame, tested successfully as fuel for simple diesel engine;
- Themycorrhizalvalue in its roots helps in getting phosphate from soilboon for acid soil;
- Improves the soil fertility throughout its life cycle;
- Its plantation generates net income for 30-35 years;
- Its medium to large plantation provide local jobs, lessening the need for local villagers to migrate to cities for the sake of employment;
- Can be intercropped with high value crops such as sugarcane, coconut palm, various fruits and vegetables, providing protection from grazing livestock and phyto-protection action against pests and pathogens;
- Its yield in un kept hedges can reacharound four tones of seed per hectare;
- Has low nutrient requirements; and
- Requires low labor inputs[16].

Environmental Values of *Jatropha curcas*

Potentialfor Enrichment of Soil and Land Reformation

*J. curcas*oil seed cake is rich in nitrogen, phosphorous and potassium and can be used as organic manure [25]. It has nitrogen (6%), phosphate (2.75%) and potassium (0.94%) and this can be used as organic manure [26]. The oil can also be used to replace synthetic fertilizers by undertaking plantations of *J. curcas*in waste lands [26]. The leaves and branches are used as manure for coconut trees and to provide plant with organic matter thereby increasing microbial activities that help in decomposition.

*Jatrohacurcas*removes carbon from the atmosphere (sequesterscarbon); store it in the woody tissues and assist in the building of soil carbon [27].Its oil seed cakes can also replace synthetic fertilizers by undertaking its plantationson wastelands. On the other hand, its leaves provide plentiful organic matter and increase the microbial activity including earthworms which is an indication of ecological improvement of a site [1,25].Therefore, it canhelp to reclaim problematic lands and restore eroded areas.

The cultivation of *J. curcas*alsoleads to the primary conservation benefits such as improved soil restoration and management. It can protect soil from erosion and plants from wind erosion [3].*J.curcas* plant can serve as live fence for the protection of soils of agricultural fields against damage by live stock because the plant acts as cost effective bio-fence as compared to wire fence. In addition to protecting crops from livestock, it reduces pressure on timber resources and increases soil moisture retention[28].*J.curcas* is chosen for this purpose mainly because it can easily be propagated by cuttings, densely planted for this purpose, and because it is not browsed by cattle[3].

There are also other potential conservation benefits from *J.curcas*. The primary conservation benefits to be derived from it productionrelate to improved soil restoration and management. For instance,the findings of Kumar et al. [28] have shown that the heavy metal contaminated soil can be restored by using combination of industrial wastes and suitable bio-inoculant strain (*Azotobacter*). Other research reports also indicated that the soil structure increased significantly after *J. curcas*was grown for 18 months in India; macro aggregate stability increased by 6-30% where as soil bulk density was reduced by 20% [29,30].Some experiences with *J. curcas* on marginal soils have also shown that it can be well established on marginal soils and can reach a reasonable production if proper care is given to boost plant growth in the initial growth phases and maintain production by additional inputs [30].

To add more organic fertilizer (from *J. curcas*seed cake) and plant density experiments (Density 1: 4x3m = 833 Pl/ha) and density 2: 3x2m=1667 Pl/ha) in India indicated strong effects on crop growth and production after 2-2.5 years of growth [31]. A *J. curcas*seed cake application of 3t / ha resulted in 1.25 t seed /ha (for density1 where the control yield 0.60t/ha) and 1.45t seed/ha (for density 2 where the control yield 0.75t/ha) [30,32].

The plant has also the potential of retaining marginal and degraded soil by reechoing the soil with its substantial root and reducing possibility of erosion [27]. With an increasing in the planting of Jatropha species, there could be substitution of fire wood by the plant for household cooking of rural areas to reduce the current rate of deforestationas well as promoting the health of rural women subjected to indoor surface pollution from cooking by insufficient fuel[27]. Studies have also showed that *J. curcas*could remediate soils contaminated with heavy metals and hydrocarbon[26,28,33].Therefore, ithas been reported that *Jatrophacurcas*isa multipurpose species for problematic sites[34].

As mentioned earlier, *J. curcas*resists drought and hence it is suitable to be propagated in arid and semi-arid areas. Therefore, it is important to rehabilitate degraded lands in water stress areas hence it has a potential to be used as green manure.As mentioned earlier, the leaves that are shed during the winter months form mulch around the base of the plant[35] and the organic matter from such leaves enhance earth-worm activity in the soil around the root-zone of the plants, which improves the fertility of the soil. This is because its leaves are rich in nitrogen, phosphorous and potassium [35]. Its seed cake too can be used as organic manure for plantations.On top of this, it has a good deal of leaf biomass that can be effectively used as shelter belt and windbreak specially in arid and semi-arid areas which are prone to both wind and water erosion. Regarding water erosion, its leaves are suitable to intercept rain drops which have the potential to create splash erosion if it falls directly on bare soil[27].

On the other hand, globalwarming (climate change) has been increasingly the worlds burning issue since its effects are being observed in different countries as flooding, storms etc.In this regard,*J. curcas*is a potential tree/shrub to combat this problem and has a direct impact on the CDM(Clean Development Mechanism) [36]. For instance,one*Jatophacurcas*tree absorbs around 8kg of CO_2 every year and at least 2500 trees can be plantedin a hectare, thus resulting in 20 tons of CO_2 sequestration per year for the life time of 40-50 years [36]. In addition to its live vegetative effect to control climate change, it has a great contribution to mitigate climate change by reducing the emission of greenhouse gasses through its use as bio-fuelby replacing the use of fossil fuels [37]. Moreover, its un-palatability by both wild and domestic animals makes it suitable to cultivate it out in the field without any extra investment for fencing and guarding [1,25].

Economic Values of *Jatrophacurcas*

Jatropha curcas has many economic advantages including many industrial applications and traditional medicine. Some of these economic advantages include:

Raw material for dye

The bark of *J. curcas*yields a dark blue dye which is used for coloring cloth, fishing nets and lines[1]. The dye may also be extracted from leaves and tender stemsand concentrated to yellowish syrup or dried to blackish brown lumpy mass. The dye imparts tocotton different shades of tan and brown[1]. Further research in this field canopen up great possibilities [1].

Food for silkworm

*J. curcas*leaves are used as food for the tussersilkworm[1]. Hence it is valuable in the production of silk[1].

Insecticide and pesticide

Extracts from all parts of*J. curcas*show insecticidal and pesticidalproperties[38]. To mention some, the seed oil and phenol esters from the oil extracted from it are used to protect from various pests and aqueous extracts from its leaves are effective in controlling *Sclerotium* spp. and*Azolla* fungal pathogen. Extracts from crushed whole seeds have also showed Molluscicidal activity against several Schistosome vector snails [39-42].Methanol extracts of *Jatropha* seed (which contains biodegradable toxins) are also being tested in Germany for the control of similar bilharzia-carrying water snails.The oil and aqueous extract from *Jatropha curcas*are also being used in the control of insect pests of cotton including cotton bollworm and on pests of pulses, potato and corn [43].Due to the above facts, thepesticidal action of the seed oil is also the subject of research of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India[43].

Contraceptive

Seeds are used as a contraceptive in South Sudan[44].The use of the oil may also cause premature abortions [44].

Alternative to Diesel

Renewable bio-fuel feedstocks are perceived to be essential contributors to the energy supply portfolio as they contribute to the world energy supply security, reducing dependency on fossil fuel resources and provide opportunity for mitigating greenhouse gases [45].For this purpose, the non-edible and drought tolerant plant species including castor, *Croton megalocarpus*and *Jatropha curcas*among others are preferred. Among these *Jatropha curcas*has been widely promoted for the past several years across dry lands for the purpose of biodiesel production[45-48].Therefore, its contribution towards biodiesel production is very high[46].

Folk Medicine

The medicinal value of plants shows that these plants have bioactive phytochemicals constituents that produce definite physiological actions on human bodies [49]. Phytochemicals could be primary and secondary constituents including common sugars, aminoacids, proteins alkaloids terpenoids and phenolic compounds [49].One of these plants which are used as traditional or folk medicine is *J.curcas*.

The applicationof*J. curcas*plant as traditional or folk medicine has been discussed by many authors. For instance, [1,50]witnessed that preparations of all parts of the plant, including its seeds, leaves and bark, fresh or as a decoction, are used in traditional medicine and veterinary purposes. It is also reported to have a lot of health benefits because of its wide range of medicinal uses [51]. The medicinal uses of this species range from external, internal and even teeth [27].Therefore it is well known that the different parts of the plant exhibit wide rangeof medicinal properties because they contain glycosides, tannins, phytosterol, flavonoids and steroidal sapogenins[33].

Accordingly, the methanol extract from J. curcasleaves showed potent cardiovascular action in animals and might be a source of beta-blocker agent for humans. Pounded leaves are applied near horses' eyes to repel flies in India[1]. The extracts of the plants are dangerous to use but water can easily release it over if not too much extract is applied[1]. The roots are used to make an antidote for snake bites [27] and their decoction is used as mouth wash for bleeding gums and tooth ache as well as for eczema, scabies and ringworm[27]. The sap flowing from the stem is used to control the bleeding of wounds. The latex of *J. curcas*contains alkaloids including jatrophine, jatropham and curcain with anti-cancerous properties [1,51]. The anti-inflammatory activity of *J. curcas*root powder in paste form, was also confirmed through the investigation conducted on albino mice [52].The oil has a strong purgative action and is also widely used for skin diseases and to soothe pain such as that caused by rheumatism [53,54].Moreover, research is underway on the potential of this plant against HIV[3,55].

Generally, experience tells us different countries use *J. curcas*for different purposes. For example, Mauritians massage ascetic limbs with the oil[56];Cameroon natives apply the leaf decoction in arthritis;Colombians drink the leaf decoction for venereal disease [56];Bahamans drink the decoction for heartburn;Guatemalans place heated leaves on the breast as a lactagogue[56];Cubans apply the latex to toothache;Colombians and Costa Ricans apply the latex to burns, hemorrhoids, ringworm, and ulcers; Barbadians use the leaf tea for marasmus;Panamanians for jaundice andVenezuelans take the rootdecoction for dysentery[56].

For food

*J. curcas*can be toxic when consumed.However, a non-toxic variety of *Jatropha*is reported to exist in some provenances of Mexico and Central America, said not to contain toxic Phorbolesters [57].Hence, *J. curcas*seed is eaten in certain regions of Mexico onceit has been boiled and roasted [58].Therefore, the non-toxic variety is used for human consumptionafter roasting the seeds/nuts, and the young leavesmay be safely eaten, steamed or stewed[59,60].

In addition to the above uses,*J.curcasa* oil gives a very good foaming, white soap with positive effects on the skin, partly due to the glycerin content of the soap. Henning [61] *J. curcas*soap is said to have medicinal characteristics and is therefore used by people with various skin diseases and sensitivity to regular soap[62].The oil is also an ingredient in hair conditioners[63]*J. curcas*oil is also used to soften leather and lubricate machinery (e.g. Chain saw). If seed cake is available in large quantities, it can also be used as a fuel for steam turbines to generate electricity. It is also used in cosmetic industries for the manufacture of candle and soap[1]. The extraction of the biodiesel aftertransesterfication of the seed oil, leads to a by-product that is glycerol which has many useful industrial applications. For example, it has been used for illumination, soap and candles [1].

To sum up *J. curcas*plant has capabilities to provide the products and services for different applications apart a diesel substitute which needs to be captured and improved. It's economically viable not only to the growers but also to the processors and end users[3]. To the rural society, the crop can create regular employment opportunities, as it provides never ending marketing potential. The research on the utilization of the by-products of *J. curcas*namely seed husk, seed kernel, glycerol, etc in the material manufacturing area needs to be explored [3].

Jatrophacurcas as an Agroforestry tree/shrub

Agroforestry is a collective name for land use system and technologies in which woody perennials are deliberately used on the same land management units as agricultural crops and/or livestock, in some form of spatial arrangement or temporal sequence or both[64]. Land-use options that increase livelihood security and reduce vulnerability to climate and environmental change are necessary and traditional resource management adaptations such as agro-forestry systems may potentially provide options for improvement in livelihoods through simultaneous production of food, fodder and firewood(energy) as well as mitigation of the impact of climate change[65,66].In this regard *J.curcas*can play a vital role by acting as multipurpose tree species and being used as a wind break, shade tree for shade demanding species, support plant for plants like vanilla ...etc.

*Jatrophacurcas*in inter-cropping and alley cropping Technology

Intercropping is growing two or more crops in the same fields simultaneously [67]. According to the topography, soil profile and prevailing agro-climatic conditions in an area, *J. curcas*can be combined with other suitable species comprising the agricultural crops, horticultural crops, herbs, pastoral and/or silvicultural components to result in an ecologically viable, economically profitable and socially acceptable agroforestry system[68]. Therefore,it is possible to improve the life conditions in rural areas and to transform the national energy scenario and the ecological landscape by evolving; promoting and adopting *J. curcas*based intercropping systems [69].

Simple and cost-effective technology of growing *J. curcas*with or without irrigation makes it promising and profitable agro forestry crop both under rain fed and irrigated conditions ensuring optimal utilization of land, man power, water and financial resources [1]. It is a crop with low capital investment, short gestation period, long productive period, unlimited employment potential in the rural areas; potential for certain of productive assets; boosting of village based industries; providing nonconventional energy in a decentralized manner and above all having a potential for wastelands development [1].

*J. curcas*can be intercropped with the following plant/tree species:

- Hedgerows of *J. curcas*with Glyricidia and Subabul
- *J. curcas*intercropped with grasses, tubers and vegetable
- *J. curcas*mixed with fruit trees
- *J. curcas*in mixed plantation with Teak/ Neem/ Karanj/ Subabul
- *J. curcas*mixed with vanila as support tree[5]
- *J. curcas*mixed with groundnuts [68]

For example, some shade loving crops like *Rouvolfiaserpentina*, *Asparagus racemosus*, *Kaempferiagalanga*, *Homalomenaaromatica*, Tulsi and *Smilax china*etcand also short durationpulses like blackgram and vegetables like tomato, bitter gourd, pumpkin, ash gourd, and cucumber can be profitably grown under *J. curcas*for the first two years. Patchouli –ashade loving aromatic herb could be a suitable intercrop for Jatropha plantation that givesfirst harvest of leaves after 4 months of planting. Vanilla can also be cultivated under it successfully [5].

Jatropha curcas can also be grownwith different plants or with other food crops like beans and maize on cultivated and on irrigated lands in rows or other arrangements[5].In alleycropping 6m distance between *J. curcas*rows is enough space for other crops to grow. The beans or other crops will grow between the rows, protected from strong winds and excessive radiation. After harvest, the root systems will deteriorate, providing the soil with nitrogen. On top of that the flowering beans or other crops will attract insects, badly needed for the pollination of the *J. curcas*plant. Many crops could be benefitted from *J. curcas* andvice versa[53].

Management of *Jatrophacurcas*

*J. curcas*has been a wild shrub species till recent yearsand focus on it has never been on oil production. Moreover, lack of benchmark descriptions on genetic variability, environment and its performance gave a little consideration on its management. Generally, its management gives emphasis on the following steps for its cultivation and production:

- Initial soil testing and audit;
- Site inspection/Assessment[14]
- Nursery establishment and management[61]
- Plantation establishment and management(including application of advanced pruning techniques)[14]
- Financial feasibility study (capital, running costs, cash flow projections)
- Advanced *J. curcas*pruning/harvesting techniques
- Location and assessment of profitable bio-fuel investment projects
- Development of Bio-Diesel Refinery and production facilities and
- Labor cost savings [61].

Much more research is required about the management of *J.*

*curcas*since it is a large drought-resistant multipurpose tree/shrub with several attributes.

Cultivation and propagation of *Jatropha curcas*

Site Preparation

Sites may initially be prepared by ploughing and disking. Individual planting pits may be prepared using hoes, and a hole that is just bigger than the plant bag is adequate[14]. Once planted, the plots should be irrigated initially to ensure the survival of the newly planted seedlings, although the species is extremely drought tolerant[14]. Nut yields are likely to be strongly influenced by available moisture, so supplementary irrigation in dry climates should improve productivity. It should be borne in mind that the trees are susceptible to water logging, especially in poorly drained soils JANUS[14]and caution should be taken not to over-irrigate. Once the trees are established, survival is usually excellent, with close to 100% survival under frost-free conditions [14].

Propagation

*Jatropha curcas*can easily be propagated from seeds by direct seeding, pre-cultivatedseedlings, transplanting of spontaneous wild plants, tissue culture and direct planting ofcuttings[70]. Unfortunately, researches have shown that plants propagated by cuttings show a lower longevity and possess a lower drought and disease resistance than plants propagated by seeds [3]. The other disadvantage of cuttings is the scarcity of material and the cost of harvesting, preparation, transport and planting of the woody stems, compared to seeds. A further disadvantage is that cuttings do not produce a taproot, meaning there is less capacity for the plant to reach soil water and nutrient reserves with correspondingly lower potential yields, although the effect of this, for different environments, has not yet been determined[3]. The absence of a taproot makes for less stability on exposed windy sites, and cuttings compete more for water and nutrients with intercrops. Seedling-raised plants would be a better choice in this situation and for agroforestry systems [3].

On the other hand,*Jatropha curcas* propagated by cuttings yield faster results than multiplication by seeds. Cuttings strike root so easily that the plant can be used as an energy-producing living fence post. Vegetative propagation has been achieved by stem cuttings, grafting, and budding as well as by air layering techniques. The investigation leads to the recommendation that cuttings should be taken preferably from juvenile plants. These vegetative methods have potential for commercial propagation of these plants[3].

In the case of *J. curcas*propagation by raised seedlings the seedlings grow very fast but they should stay in the nursery for 3 months until they are 30 - 40 cm tall[71]. By then, the plants have developed their repellent smell and will not be browsed byanimals [70]. At this stage, they should be moved out ofthe nursery to allow them to acclimatize before planting. In this case watering of the plants is required. The best time for planting is the warm season before or at the onset of the rain[71].

The choice of propagation method depends on use. Plants propagated fromseeds are generally preferred for the establishment of long-lived plantationsfor oil production. Land preparation is a prerequisite for direct planting of *J. curcas*. In the case of heavy soils, deep plowing is given whereas in light soils, shallow plowing is enough[1].Direct sowing should only be used in areas with high rainfalland the seeds must be sown after the beginning of the rainy season. In the case of seed sowing two seeds should be put at each spot. When the seedlings are 4 weeks old, weaker seedlings should be removed and one healthy seeding is left on each spot and the removed seedlings could be used for gap filling[1].

Forquick establishment of hedges and plantations for erosion control, directlyplanted cuttings are best. Cuttings of 30 cm length have been found to havethe highest survival rate [70]. The recommended planting widths are2x2 m, 2.5x2.5 m and 3x3 m, which isequivalent to crop densities of 2,500, 1,600 and 1,111 plants/ha, respectively[12]. The 2mx2m spacing will accommodate 2500 plants/ha under irrigated or partially irrigated conditions. On rain fed wastelands, high density plantations at 2m x 1m or 1.5m x 1.5m accommodating 5000 or 4444 plants per hectares respectively, is desirable [1].

*J. curcas*can also be propagated by tissue culture. This method is a laboratory-based which uses artificial and sterilized propagation media.Tissues from various plants can be used in this procedure which allows asexual propagation of plants with desired characteristics[72]. In order to obtain a higher rate of survival of planting materials, it is important to establish a nursery that is accessible to the plantation that has a source of water[72].

Care to be taken after planting

*J. curcas*has fast growth once it is established out in the field. We can get one-meter tall leading shoot in fivemonths' time[73].

Weeding

Weeding is required regularly before the ground is shaded by the developing leaf canopy to avoid completion with other plants. The cut weeds may be left as surface mulch for water conservation. In addition to mulching by weeds or other materials, digging contour trenches and basins around individual plants aids water entrapment and infiltration in semi-arid regions [73].

Pruning and trimming

To give a bushy shape the plant should be trimmed during spring (Feb-March) up to 5 years including one pruning when the plants attain 1.5 m height. Pruning during the dry or dormant season is important to increase branching and the number of tip-borne inflorescences, as well as to form a wide low-growing tree that is easier to harvest[73].The stem and branches may be pinched out at six months to encourage the development of laterals and the main stem cut back to 30-45 cm[73]. The branch tips are pruned again at the end of the first year. In the second and subsequent years, branches are pruned by removing around two-thirds of their length. After ten years, it is recommended to cut trees down to 45 cm stumps to improve yields. Re-growth is rapid and trees will start bearing again within a year [73]. Flowers require the presence of pollinating insects. Thus, it may be beneficial to place hives for honey bees in the proximity[73].

Figure 6: *Jatropha curcas*seedlings (Source: http://www.jatrophacurcas-plantations.com/).

Harvesting and Processing

Harvesting

The flowering in *J. curcas*is induced in rainy season and bears fruits and matures in winter. Flowering is less and delayed when grown in shady conditions. In sunny condition flowering is more and early[6]. Seedlings produce flowers 9 months after planting. However, plants established through cuttings produce flowers from 6 months onwards. But economic yield starts from the end of third year after planting [6].Under good rainfall conditions, *J. curcas*starts producing seeds within 12-18months but reaches its maximum productivity level after 4 to 5 years. For mature plants, 2-3 tons of seeds/ha can be achieved in semi-arid areas, although yields of 5 tons/ha are routinely achievable under more favorable(wetter) conditions [24].

To get the best result it is good to harvest the fruits when their color turned yellow to dark brown approximately 2 to 3 months after flowering. Seeds should be collected when the capsules have split open [74].Collection is bestdone by picking fruits from the tree or hitting and shaking the branches till thefruits break off. Seeds collected from live fences can normally be reached byhand. For taller trees, it is possible to collect the fruits in a small bag that isattached to a stick. The dried pods are collected and seeds are separated either manually or mechanically. Seeds are dried for 4-5 days to reduce moisture level 10% before packing [70,74]

On the otherhand,it has been reported that direct sunlight has a negativeeffect on the viability of collected seed, so seeds should be dried in the shade[70].The seeds are oily and do not remain viable for long (one year at most). Useof fresh seeds improves germination, which should take about 10 days withgood moisture conditions. In terms of harvesting, for medicinalpurposes, the seeds are harvested as needed, but for energy purposes,seeds might be harvested all at once [17].

Yields depend on agro ecological conditions; soil conditions, altitude, temperature, water availability and management regimes. The seed yields reported for different countries ranged from 0.1 to 15 tons ha-1 year-1 [3,34].While Tewari[75], estimates annual seed production of between 200grams to 2kg per plant depending on the conditions under which *J. curcas*is cultivated. Although*J. curcas*is said to grow in marginal areas it is not nitrogen fixing and hence requires nitrogen rich soil for good seed production[3].

Production of Oil

Generally, bio-fuels represent a potential mechanism for catalyzing rural livelihoods. Much of the income generation from bio-fuels production can be retained locally and can help to reduce rural poverty in contrast to fossil fuels or central electricity production and distribution systems, and in to other renewable energy technologies[81]. Finally, the remaining press cake of *J. curcas*seeds after oil extraction could also be considered for energy production.

There are a few different methods for purification of biodiesel found from J. curcasoil, including washing, heating, and the addition of catalyst. The biodiesel layer has traces of excess methanol and catalyst. Methanol can be removed by evaporation and catalyst can be removed by washing[78]. Water is a solvent that will dissolve catalyst and methanol and separate from the oil after being mixed, so it was used as a washing element. The biodiesel layer was washed three times. This procedure is a common one used by mixing and then separating the water[78].The final step was to ensure that the biodiesel was dry. All that is needed for this is heating to remove water left from the washing[78].

There are three ways to purify the oil:

a. Sedimentation: Even though it takes long time up to one week until the sediment is reduced to 20-25 % of the volume of the raw oil, it is the easiest way to get clear oil[78].

b. Boiling with water: It is boiling the oil in water which is 20% of the total volume until all the water is evaporated(no bubbles of water vapor any more). After a few hours, the oil becomes clear[78].

c. Filtering: passing the raw oil through a filter is another oil purifying method though it is a very slow process and has no advantage in respect of sedimentation[78].

Storage

J. curcasseeds and seed oil quality may get deteriorated on storage due to bacteria, moles, enzymatic degradation, oxidation, and hydrolysis. Therefore, it is important to understand the effect of storage conditions on quality of oil in order to optimize the economically viable storage conditions for storage of oil. For plant oil storage, the following conditions are favorable[79]: -

- Low total impurities in the oil
- Cool storage temperature
- Avoiding temperature variations (and hence water condensation)
- Darkness
- Contact with fresh air

Easy to clean tanks [79] Furthermore, the following parameters are important for J. curcasoil to be used for bio-diesel production before storage[80,81].

- Moisture content: The oil must be moisture-free for catalyst-based trances terification process because every molecule of water destroys a molecule of the catalyst, thus decreasing its concentration.
- Free fatty acids(FFA): The FFA content should be less than one per cent. It has been observed that the lesser the FFA in oil the better is the bio-diesel recovery.
- Iodine value(IV): The degree of unsaturated fats can be measured as IV. High IV is preferred to lower the cloud point. However, an IV of more than 25 limits the use of oil as neat fuel due to its potential to polymerize[79-81].

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*Jatrophacurcas*oil production potential in Ethiopia

Emerging economies with vast unproductive lands and tropical climates like Ethiopia can benefit greatly from the renewable energy resources such as *J. curcas*[82,83]. Besides productively utilizing the lands available, it is highly likely to be more adaptable for the community bearing in mind abundant labor availability in the country[82,83].

Being a perennial crop, *J. curcas*would ensure a regular income to communities that are used to have fluctuations in their income streams. The plant is capable of growing in the poorest rocky soils and sand dunes which will primarily use as stabilizing the area[83]. Three *J. curcas*plants can planted within one row in one-meter interval then within two rows six plants can be planted. On average in one farm holding about 1200 trees can be planted and as fence also from 300 to 600 *J. curcas*plants can be planted. Hence at least 2000kg *J. curcas*seeds can be easily produced. About 40% of the seed weight is oil. Therefore, about 800litres of oil can be produced from one farmer's holdings. Accordingly, farmers can use the oil for different purposes and they may sell it for biodiesel producing companies as a result they can benefit Ethiopian [84]. Where most of its qualities suit Ethiopian context and could benefit in many ways and would also help in poverty reduction endeavor. Its credibility in carbon trading could also earn more money for the growers[83,84].

On the other hand, Ethiopia on average imports about 1 billion liters petrol diesels. With the participation of 1.25 million farmers in biodiesel production program the import of 1 billion liters of petrol diesel can be substituted with biodiesel. At the same time by involving biodiesel producing companies the production will be in excess of local consumption and this will be a good commodity for export[83,84].

The renewable fuel may lead developing countries like Ethiopia in reducing emissions from deforestation, improving energy efficiency, and transforming urban transport. Such an approach can simultaneously support economic recovery and encourage growth in areas that mitigate the impact of climate change[37]. Besides the economic advantages discussed earlier,the potentials of *J. curcas*for reclamation of marginal or eroded soil is supported by scientific literature [29]. As the plant is said to be drought tolerant, rural and remote areas in Ethiopia could benefit from it to improve their access to sustainable energy as well as for reclamation of marginal or degraded soils[83,37].

Factors affecting the potential of *J. curcas*production

There are some criticismson *J. curcas*since it is feared that its production will lead to competition with food crop production and increased pressure on land[83,85]. There is also a recent study in East Africa that revealed*J. curcas*production, is not economically viable for smallholder's due to low and unreliable yields and unreliable markets [86-89].The opportunity costs of land and investment risks are also high, as *J. curcas*needs long time(5-8years) to reach maturity. Hence,as*J. curcas*has manyadvantages, its limitations must not be ignored. Some of its otherlimitationsinclude:

Toxicity of seeds and leaves

The plant and its seeds are toxic to both animals and humans. It is highly poisonous if taken especially in higher quantities[90]. Much like other members of the family Euphorbiaceous, *J. curcas*plants contain several toxic compounds, including lectin, saponin, carcinogenic phorbol esters, and a trypsin inhibitors which make complete detoxication a complicated and difficult process[91,92]. The seeds of this genus are also a source of the highly poisonous toxalbumin(curcin)[93].Despite this, the seeds are occasionally eaten after roasting, which reduces some of the toxicity. Its sap is a skin irritant, and ingesting as few as three untreated seeds can be fatal to humans[93].The poisoning is irritant, with acute abdominal pain and nausea about half an hour following ingestion. Diarrhea and nausea continue but are not usually serious. Depression and collapse may occur, especially in children. Two seeds are strong purgative. Four to five seed are said to have caused death, but the roasted seed is said to be nearly harmless[93].

Its potential to be weedy

*J. curcas*has the potential to be weedy because of its seeds that can spread rather easily and create dense stands on uncultivated lands. It is reported as a weed in many places including Australia[94,95] Brazil, Fiji, Honduras, India, Jamaica, Panama, Puerto Rico, and Salvador.It is a quarantine pest for Australia and South Africa [63,96].

Attack by insects

The other constraint to the production of *J. curcas*is its vulnerability to be attacked by insect pests and diseases.*J. curcas*is thought to be toxic tomany microorganisms, insects and animals. Despiteits toxicity, *J. curcas*itselfis not pest and disease resistant. Globally more than 40 species of insects affecting *J. curcas*have been reported[93]. For instance, the following major pests and diseases affectingitin the lower valley of the Senegal river havebeen identified: the leaf miner Stomphastisthraustica,the leafand stem miner Pempeliamorosalis[93]and the shield-backed bugCalideapanaethiopicawhich can cause flower and fruitabortion. Series damage by Nephoptery larvae was observed at Pusa and Mandalay recorded more than dozen pests occurring in *J. curcas*[93].

Figure 8: Life cycle of S. thraustica(Source: Devi et al.,2008).

The adults (A) lay their eggs on the *Jatropha*leaves. The larvae (B) dig tunnels in the leaf blade, which cause the leaves to dry out (C). Pupation takes place on the leafsurface (D), where the pupae enclose themselves in characteristic small white webs, which give the foliage a speckled appearance (E). Devi have also reported that the two insect pests that are emerging as a major problem in *J. curcas*cultivation are scutellarid bug (*Sctelleranobilis*Fabr that causes flower fall, fruit abortion and malformation of seeds and Pempeliamorosalisthat causes webbing of inflorescence and capsule damage).

Lack of efficient oil extraction and processing methods

The other constraint is the unavailability of efficient oil extraction methods. *J. curcas*oil does not store well without processing perhaps for only a few months; therefore, this would make it difficult to provide fuel to power the year around [93].

Conclusion

The diversified uses of *J. curcas*outweigh its disadvantages since it is used for soil conservation[37], rehabilitation of degraded lands, in agroforestry practices like intercropping, live fence, windbreak and as a shade tree,as traditional medicine and many other applications.These advantages increase its acceptance hence give it chance to be cultivated and propagated. Of the advantages of *J. curcas*, its use in biodiesel production takes a large part and gets a due consideration both in developed and developing countries. This is because using biodiesel for generating energy than fossil fuels has a dual purpose i.e. saving money which would have been spent for the costly fossil fuels and reducing the emission of greenhouse gases which bring climate change. Multiple benefits of *J. curcas*plantsnot only useful in saving the environment from pollution but also play important role in employment generation and entrepreneurship for the rural people. Potential use of *J. curcas* as an energy crop, in agroforestry, in soil conservation measures and industrial application are the good opportunities to cultivate the plant in the unused and barren land. The input required for raising *J. curcas* plant to harness oil is very minimal, which reduces the investment required to generate a unit quantity of bio-fuel.

On the otherhand, *J. curcas* has some disadvantages and limitations for its vast production and uses. For instance, studies show it not economically viable for smallholders due to low and unreliable yields and unreliable markets, it has opportunity costs of land and investment risks due to long timeto reach maturity. Moreover, its toxicity to both livestock and humans and other limitations may seem to affect its production. But the opportunity costs can be avoided to a great extent if*J. curcas*is grown as a hedge or a live fence to protect crops, or to corral grazing areas. It is also possible to create market access to make smallholder farmers get the benefit from production of*J. curcas*seeds besides its use as live fence.Smallholder farmers must also getawareness about its potential for local energy production. Therefore, the question remains whether *J. curcas*hedges can play a good role, not necessarily as a cash crop, but in enhancing the access of households to locally produced energy, without causing opportunity costs of land and labor, while at the same time reducing costs for the purchase of other fuels[46].The other disadvantages mentioned such as its toxicity, its potential to be weedy, attack by insects and absence of well-developed oil production and processing methods can be managed by creating a paradigm shift towards improvement and alleviation of problems.

As to the management of *Jatropha curcas*, though it can be propagated everywhere; on degraded soils, waste lands and marginal lands but it requires good management for the production of high quantity and quality seed and oil. The managements could be watering (irrigation) at the time of water stress, manure and fertilizer application as required, pruning and trimming to get vigorous growth and good seed yield. It is also crucial to protect it from pests and diseases which reduce its seed and oil production capacity.

Finally, we can conclude that *J. curcas*is a "Miracle Tree" and certainly a highly interesting plant with potential uses, particularly as bio-fuel to help in combating the energy crisis throughout theworld and generate income in rural areas of developing countries. With proper care and attention to its managementthe crop can create regular employment opportunities to the rural society as it provides never ending marketing potential. Hence, like any other crop cultivated for any purpose*J. curcas*requires proper management such as proper planting techniques,pruning,pest and disease control, proper genetic selection, commercial cultivar development, adapted cultivars for target growing areas,proper crop inputs (compost, manure, chemical fertilizer etc.as required) and watermanagement.The research on the utilization of the by-products of *J. curcas* namely seed husk, seed kernel, glycerol, etc. in the material manufacturing area also needsbe explored.

Personal Reflections

From the revised literatures, it is seen that *J. curcas*has many applications in rehabilitation of degraded lands, traditional medicine, agro-forestry(as wind break,livefence etc.), bio-fuel(replacing fossil fuels) and has great role in climate change adaptation and mitigation. In this regard, the Ethiopian Environment and Forest Research Institute has a plan to undertake so many new projects under its directorates of which one is the plantation and agro forestry directorate. Under the plantation and agroforestry directorate,rehabilitation of degraded lands case team hasproposed a new project entitled "Developing Technologies andinformation to Rehabilitate Degraded Lands" and needs *J. curcas*to be one of the candidate species for the research to rehabilitate moisture stress areas, degraded stony soils and nutrient depleted degraded areas as this shrubby tree species with stands all the aforementioned stresses for plant growth.

References

1. Gubitz GM, Mittelbach M, Trabi M (1999) Exploitation of the tropical oil seed plant *Jatropha curcas*L. BioresourcesTechnol 67: 73-82.
2. Dehgan B (1984) Phylo genetic Significance of Interspecific Hybridization in *Jatropha* (Euphorbiaceae). Systematic Bot 9:467-478.
3. Heller J (1996) Physic nut. *Jatropha curcasL.*Promoting the Consrvation and use of Underutilized and Neglected crops. Intitute of plant genetics and crop plant Research (IPGRI), Gatersleben/ International Plant Genetic Resources Institute, Rome, Italy, P66.
4. KAKUTE (2006) Jatropha Project in Monduli District, Arusha Region.
5. Nyamai DO,Omuodo LO (2007)*Jatropha curcas*.The untapped potential in Eastern and Central Africa. Production and utilization manual. Trees on Farm Network (TOFNET).
6. Dehngan B, Webster GL (1979)Morphology and Intragenic Relationships of the Genus*Jatropha*(Euphorbiaceae). 74. University of California publications in Botany.
7. Jongschaap REE, Corré WJ, Bindraban PS, Brandenburg WA (2007)Claims and Facts on *Jatrophacurcas*L. Global J*atropha curcas*evaluation, breeding and propagation programme.Wageningen U.R. Report 158. Plant Research International B.V.
8. Pratt JH, Henry EMT, Mbeza HF, Mlaka E, Satali LB (2002) Malawi Agroforestry Extension Project Marketing & Enterprise Program. Main Report. MalawiAgroforestry Publication No 47:44-46.
9. Achten WMJ, Nielsen LR, Aerts R, Lengkeek AG,Kjaer ED (2010) Towards domestication of *Jatrophacurcas*.Biofuels1: 91-107.
10. King AJ, He W, Cuevas JA, Freudenberger, Ramiaramanana D (2009) Potential of *Jatropha curcas* as a source of renewable oil and animal feed: Review paper. Journal of Experimental Botany60: 2897-2905.
11. World Agroforestry Centre (2007) When oil grows on trees World Agroforestry Centre press release.
12. ICRAF (2003) *Jatropha curcas*. Agroforestree Database.
13. Pacific Island Ecosystems at Risk (PIER) (2004).
14. JANUS (2004) JANUS Foundation - A small report on *Jatropha curcas.*
15. LeleSV (2004) The cultivation of *Jatropha curcas*(Ratnajyot.
16. Henning R (1996) Combating Desertification: The Jatropha Project of Mali,West Africa. In: The Arid Lands Newsletter, 40 (Fall/Winter 1996).
17. DukeJA (1983) Handbook of energy crops.
18. Katwal RPS, Soni PL (2003) Biofuels: an opportunity for socioeconomic development and cleaner environment. Indian Forester 129: 939-949.
19. HolmLG,PanchoJV,HerbergerJP,Plucknett DL (1979) A geographical atlas of world weeds.
20. Kandpal JB, Mira M (1995)*Jatropha curcas*: A Renewable Source of Energy for Meeting Future EnergyNeeds Renewable Energy. Elsevier Science 6:159-160.
21. Ginwal HS, Phartyal SS, Rawat PS, Srivastava RL (2005) Seed source variation in morphology, germination and seedling growth of *Jatropha curcas*Linn., in Central India. SilvaeGenetica 54: 76-80
22. Daniel B, Solomon A, Wossen K (2009) Laboratory Manual for Plant Products analysis. Ethiopia Institute of Agricultural Research 1.
23. Openshaw K (2000) A review of *Jatropha curcas*: an oil plant of unfulfilled promise. Biomass and Bioenergy19: 1-15.
24. Becker K, Makkar HPS(2000)*Jatropha* and *Moringa.*
25. Staubmann R, Foidl G, Foidl N, Gübitz GM, Lafferty RM, et al. (1997) Biogas production from *Jatrophacurcas* press-cake. ApplBiochemBio-technol 63-65:457-67.

26. Agbogidi OM, Mariere AE, Ohwo A (2013) Metal concentration in plant tissues of *Jatropha curcas*L grown in crude oil contaminated soil. Journal of Bioinnovation2: 137-145.

27. Agbogidi OM, Ekeke EA (2011)*Jatropha curcas*: Linn an important but neglected plant species in Nigeria. Journal of Biological and Chemical Research 28: 52-62.

28. Kumar GP, Yadav SK, Thawale PR, Singh SK, Juwarkar AA (2008) Growth of *Jatropha curcas*on heavy metal contaminated soil amended with industrial wastes and *Azotobacter*-a green house study. BioresourTechnol 99: 2078-2082.

29. Spaan WP, Bodnár F,Idoe O, de Graaff J (2004) Implementation of contour vegetation barriers under farmer conditions in Burkina Faso and Mali. Quarterly Journal of International Agriculture 43: 21-38.

30. Chaudhary D, J Patolia A, GhoshJ, ChikaraG,Boricha, et al.(2007) Changes in soil characteristics and foliage nutrient content in *Jatropha curcas* plantation in relation to stand density in Indian wasteland. In: FACT seminar on *Jatropha curcas* L. agronomy and genetics.

31. Ghosh A, J Patolia, D Chaudhary, JChikara, S Rao, D Kumar, et al.(2007)Response of *Jatropha curcas*under different spacing to *Jatropha de-oiled cake*. In: FACT seminar on *Jatropha curcas* L. agronomy and genetics 8: 26-28. FACT Foundation. Wageningen, The Netherlands.

32. Kumar A, Sharma S (2008) An evaluation of multipurpose oil seed crop for industrial uses: A Review. Indus Crops Prod 28: 1-10.

33. Agbogidi OM, Eruotor PG (2012) Morphological Changes due to spent engine oil contamination and its heavy metal components of *Jatropha curcas.* In: Baby, S. and Sandhu, P.S. eds. Proceedings of the International Conference on Bioscience, Biotechnology and Health Sciences ICBBHs'.

34. Jones N, Miller JH (1993)*Jatropha curcas*: a multipurpose species for problematic sites. Washington DC. A World Bank paper 1.

35. Azene Bekele, Ann Birnie, Bo Tengnas (1993) Use full trees and Shrubs forEthiopia.Regional Soil conservation unit(RSCU), Swedish International Development Authority.

36. Romijn HA (2011) Land clearing and greenhouse gas emissions from *Jatropha* bio-fuels on African Miombo Woodlands. Energy Policy 39: 5751- 5762.

37. Bach S (2012) Potentials and Limitations of *Jatropha Curcas* as a Multipurpose Crop for Sustainable Energy Supply and Soil and Water Conservation: A Case Study in Bati, Ethiopia, Using the WOCAT Approach [Master's thesis]. Bern, Switzerland: University of Bern.

38. Grainge M, Ahmed S (1988) Handbook of Plants with Pest-control Properties, Wiley-Interscience, New York.

39. Nath LK, Dutta SK (1992) Wound healing responses of the protelytic enzyme curcain. Indian JPharmacol 24: 114-115.

40. Consoli RAGV, Mendes NM, Pereira JP, Santosh VS, Lemounier MA (1989) Influence of several plants extracts on the oviposition behaviour of Aedisfluviatilis (Lutz) in the laboratory. Memorias-Do-Instituto-Oswaldo-Cruz 84: 47-52.

41. Jain C, Trivedi PC (1997) Nematicidal activity of certain plants against root-knot nematode, Meloidogyne incognita infecting chickpea. Annals of Plant Protect Sci 5: 171-174.

42. Meshram AB, Kulkarni N, Joshi KC (1994) Antifeedant activity of certain plant products against teakskeletonizer, Eutectonamachaeralis Walk. Ann Entomol 12: 53-56.

43. Kaushik N, Kumar S (2004)*Jatropha curcas*L. Silviculture and Uses. Agrobios (India), Jodhpur.

44. Nayak BS, Patel KN (2010) Pharmacognosis studies of *Jatropha curcas*leaves. *International Journal of Pharmtech Research*2:140-143.

45. Van Eijck JAJ (2006) Transition towards biofuels in Tanzania. An analysis of strategic niche management. Msc Thesis, Eindhoven University of technology,Eindhoven.

46. Van Eijck JAJ, Smeets E, Romijn H, Balkema A, Jongschaap R (2010)*Jatropha*Assessment. Study carried out in the framework of the Netherlands Programme Sustainable Biomass by the Copernicus Institute, Utrecht University, Technical University, Eindhoven and Plant Research International, Wageningen UR.

47. WiskerkeW (2008) Towards A sustainable biomass energy supply for rural households in rural Shinyanga, Tanzania. A cost benefits analysis. Master's thesis Utrecht University.

48. Loos, Tim Kagiso (2009) Socio-economic Impact of a Jatropha-Project on Smallholder Farmers in Mpanda, Tanzania: Case Study of a Public-Private-Partnership Project in Tanzania. Master Research paper,University of Hohenheim, Institute for Agricultural Economics and Social Sciences in the Tropics and Subtropics.

49. Sofowora A (1993) Medicinal plants and traditional medicine in Africa. Spectrum Books Ltd,Ibadan. 289.

50. Dalziel JM (1955) The Useful Plants of West-Tropical Africa. Crown Agents for Oversea Governments and Administration, London147.

51. Thomas R, Sah NK, Sharma PB (2008) Therapeutic biology of *Jatropha curcas*: a mini review. Curr Pharm Biotechnol 9: 315-324.

52. Mujumdar AM, Misar AV (2004) Anti-inflammatory activity of *Jatropha curcas* roots in mice and rats. J Etnopharmacol 90:11-15.

53. Henning RK (2003) The Jatropha Booklet: A guide to Jatropha Promotion in Africa.BaganiGbR, Weissensberg,Germany5-33.

54. Igbinosa OO, Igbinosa EO, Aiyegoro OA (2009) Antimicrobial activity and phytochemical screening of stem bark extracts from *Jatropha curcas* (Linn). African Journal of Pharmacy and Pharmacology 3: 58-62.

55. Marroquin EA, Bainco JA, Granados S, Caceres A, Morales C (1997) Clinical trial of *Jatrophacurcas*in treatment of common warts. Fitoterapia, 68:160-162.

56. Morton JF (1981) Atlas of medicinal plants of middle America:Bahamas to Yucatan. Charles C. Thomas, Springfield, USA 1420.

57. Makkar HPS, BeckerK, Schmook B (1998) Edible provenances of *Jatropha curcas*from Quintana Roo state of Mexico and effect of roasting on antinutrient and toxic factors in seeds.Plant Foods Human Nutr 52: 31-36.

58. Delgado Montoya JL, Parado Tejeda E (1989) Potential multipurpose agroforestry crops identified for the Mexican Tropics. In: Wickens GE, Haq N, Da P (Eds.), New Crops for Food and Industry. Chapman and Hall, London166-173.

59. Ochse JJ (1931) Vegetables of the Dutch East Indies. A. Asher and Co., Hacquebard, Amsterdam.

60. Sujatha M, Makkar HPS, Becker K (2005) Shoot bud proliferation from axillary nodes and leaf sections of non-toxic *Jatropha curcas*L. Plant Growth Regulation 47: 83-90.

61. Henning RK (2000) The Jatropha Manual:A guide to the integrated exploitation of the *Jatropha* plant in Zambia. BaganiGbR. Produced for GTZ. GTZ-ASIP-Support-Project Southern Province, Choma

62. Messenmaker L (2008) The Green Myth? Assessment of the Jatropha value chain and its potential for pro-poor bio-fuel development in Northern Tanzania. MSc thesis. International Development Studies (IDS) at the Faculty of Geosciences, Utrecht University, The Netherlands 45.

63. Brittaine R, NLutaladio (2010)*Jatropha*: A Smallholder Bioenergy Crop. The Potential for Pro-Poor Development. Food and Agriculture Organization of the United Nations, Rome.

64. LundgrenBO, aintreeJB (1982) Sustainedagroforestry.In:Nestel,B.(ed.),Agricultural Research for Development: Potentials and ChallengesinAsia37-49.ISNAR,TheHague, The Netherlands.

65. Kumar A, MS Hooda, Bahadur R (1998) Impact of multipurpose trees on productivity of barley in arid ecosystem. Ann. Arid Zone37: 153-157.

66. Kursten E (2000) Fuelwood production in agroforestry systems for sustainable land use and CO_2 mitigation. Ecological Engineering 16: 69-72.

67. Sangakkara UR, WRichner, MKSchnider, P Stamp (2003) Impact of Intercropping beans (*Phaseolusvulgaris* L.) and sunhemp (*Crotalarajuncea* L.) on growth, yields and nitrogen uptake of maize (*Zea mays* L.) grown in the humid topics during the minor rainy season. Maydica 48: 233-238.

68. Singh RN,Vyas DK, Srivastava NSL, Narra M (2008)SPERI experience on holistic approach to utilize all parts of *Jatropha curcas*fruit for energy. Renewable energy33: 1868-1873.

69. OCAR (Agricultural and Rural Development Department) (2002) Appraisal Report on Community Forestry Management Project.

70. Joker D, Jepsen J (2003)*Jatropha curcas*L. Danida Forest Seed Centre (DFSC) Seed Leaflet 83: 2.

71. Jones N, Miller JH (1992)*Jatropha curcas:* a multipurpose species for problematic sites. World Bank, Washington DC,USA, ASTAG Technical Papers Land Resources. 1:40.

72. Datta MM, Mukherjee P, Ghosh B, Jha TB (2007) *In vitro* clonal propagation of biodiesel plant; Current science, 93: 1438.

73. Gour VK (2006)Production practices including post-harvest management of *Jatropha curcas*. In: Singh, B., R. Swaminathan and V. Ponraj editors. Proceedings of the biodiesel conference toward energy independence-focus of *Jatropha*, Hyderabad, India. RashtrapatiBhawan, New Delhi. 223-251.

74. Singh G, Seetharaman SP, Chockshi SN (1996) A study into the production and marketing of *Jatropha curcas*. Ahamedabad: Centre for Management in Agriculture. Indian Institute of Management.

75. Tewari DN (2007) Jatropha & Biodiesel. 1st Ed. New Delhi, Ocean Books Ltd.

76. Ofori-Boateng C, Teong LK, Jitkang L (2012) Comparative energy analyses of *Jatropha curcas* oil extraction methods: Solvent and mechanical extraction processes. Energy Conversion and Management55: 164-171.

77. Jiang L, Hua D, Wang Z, Xu S (2010) Aqueous enzymatic extraction of peanut oil andprotein hydrolysates. Food and BioProducts Processing 88: 233-238.

78. Chromic (2002) Distillationof Safrole.

79. Hynd A, Smith A (2004) Meeting a Pressing Need: Project Appraisal of the Oilseed Ram Press and Approaches to Implementation. Design for Developing Countries Case Study Series, Issued October 20, 2004.

80. Adriaans T,Jongh de J (2007) *Jatropha* oil quality related to use in diesel engines and refining methods, FACT foundation.

81. Ferchau E,Ansø N (2000) Equipment for decentralised cold pressing of oil seeds, Folkecenter for renewable energy, 2000Archive Kakute/ Diligent Tanzania Ltd., 2004.

82. Suri T, Tschirley D, Irungu C, Gitau R, Kariuki D (2008) Rural incomes, ineaquality and poverty dynamics in Kenya. Tegemeo Institute of Agricultural Policy and Development, Egerton University.

83. Ehrensperger A, Wörgetter M, Moraa V, Sonnleitner A(2013) Can Jatropha Improve the Energy Supply of Rural Households in Africa? *Jatropha* Facts Series,3ERA-ARD.

84. Ethiopian Ministry of Mines and Energy (2007) The Bio-fuel Development and Utilization Strategy of Ethiopia.

85. Cotula L, Finnegan L, Macqueen D (2011)Biomass energy: Another driver of land acquisitions? The global land rush. lied briefing. London: International Institute for Development and Environment.

86. Iyama M, Zante P, Munster C, New Man D, Onchieku J, et al. (2009) Jatropha Reality-check. A field assessment of the agronomic and economic viability of *Jatropha* and other oilseed Crops in Kenya. Endelevu Energy, World Agroforestry Centre, Kenya Forestry Research.

87. Findlater KM,Kandlikar M (2011)Land use and second-generation biofuel feedstocks: The unconsidered impacts of *Jatropha* biodiesel in Rajasthan. IndiaEnergy Policy 39:34004-3414.

88. Feto A (2011) Energy, Greenhouse Gas and Economic Assessment of Biodiesel Production from *Jatropha*: The Case of Eastern and North-eastern Ethiopia[Master's thesis]. Alemaya, Ethiopia: Haramaya University.

89. Mogaka V, Iiyama M, Ehrensperger A, Birtel M, Gmünder S (2012) Understanding adoption of *Jatrophacurcas*L. by smallholders in Kenya. The examples of Bondo, Kibwezi and Kwale districts.

90. Joubert PH, Brown JM, Hay IT, Sebata PD (1984) Acute poisoning with *Jatropha curcas*(purging nut tree) in children. S Afr Med J 65:729-730.

91. Haas W, Strerk H, Mittelbach M (2002) Novel 12-Deoxy-16-hydroxyphorbol diesters isolates from the seed oil of *Jatropha curcas*. Journal of Natural Products 65: 1434-1440.

92. Endo Y, Tsurugi K (1987) RNA N-glycosidase activity of ricin A chain. Mechanism of action of the toxic lectin ricin on eukaryotic ribosomes. Journal of Biological Chemistry 262: 8128-8130.

93. Benge M (2006)Assessment of the potential of *Jatropha curcas*, (biodiesel trees) for energy production and other uses in developing countries. Senior Agroforestry officer, USAID (Ret.)

94. Northern Land Manager (2011) Managing weeds for wildlife conservation - Physic Nut, *Jatropha curcas*. Territory Natural Resource Management / Charles Darwin University.

95. University of Queensland (2011) Weeds of Australia. Biosecurity Queensland Edition. QueenslandGovernment,Australia.

96. Parsons WT, EG Cuthbertson (2001) Noxious Weeds of Australia (Second). CSIRO Publishing, Collingwood. 698 pp.