Chapter 16

Jatropha curcas Biodiesel, Challenges and Opportunities: Is it a Panacea for Energy Crisis, Ecosystem Service and Rural Livelihoods?

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Introduction

The current worldwide energy crisis and associated pollution causing global warming are largely due to extensive dependence of energy supply on conventional fossil fuels. Present scenario of depleting world's fossil fuel reserves, increased consumption, rising prices of petroleum products at unprecedented levels, dependence on non-renewable sources and its substantial contribution to environmental pollution and global warming have led researchers, policy makers, environmentalists and industrialists to consider the importance of biofuels such as biodiesel in search of alternatives to existing limitations (Wani et al. 2006). The burgeoning population, fast growing industry and energy hungry new technologies further increase the urgency to look for alternatives to existing limitations. It is estimated by the International Energy Agency (IEA) that increasing population along with increasing incomes in developing countries will contribute a share of 74% to the increase in global primary energy use. India and China will be responsible for 45% of this increase. For India, one driver behind the growing order for energy is the transport sector that currently consumes 27% of total primary oil demand. This share will increase to 47% by 2030 (IEA 2007). Diesel makes up almost 70% of the oil used in Indian road transport. Biodiesel among biofuels is a renewable source of energy, therefore it offers a great potential and mitigate limitation and supplement supplies of fossil fuel and at the same time minimize C emissions. Biofuel and biodiesel, in particular, are derived from biomass and use photo-synthetically fixed C, thus, facilitating recycling of atmospheric CO_2. Meeting the energy requirements by using environment-friendly biofuels will help to decrease the carbon dioxide emission into the atmosphere.

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N. Carels et al. (eds.), *Jatropha, Challenges for a New Energy Crop: Volume 1: Farming, Economics and Biofuel*, DOI 10.1007/978-1-4614-4806-8_16,

Biodiesel from *J. curcas* (hereafter referred to as Jatropha) seed oil is considered as an answer to energy crisis, which can replace depleting fossil fuel and at the same time render environmental services by way of maintaining or reducing CO_2 levels. It also helps in creating other environmental benefits, such as rehabilitation of degraded lands through addition of organic matter through leaf fall, hedge for erosion control and wind break. After extracting oil, the deoiled cake serves as a rich source of organic matter and plant nutrients for crop production. Switching over to biodiesel will have implications in terms of employment generation for various production and market related activities and decentralized energy affecting rural livelihoods. Biodiesel can be a decentralized source of energy through its use in electricity generator, thus addressing the issue of erratic supply in farms with large productivity and use in other domestic or power based livelihood activities. So, we are today facing a question—is Jatropha truly a wonder biodiesel plant, which can be a panacea for issues of depleting fossil fuels, environmental degradation and main streaming of the poor?

Jatropha, the Potential Plant for Biodiesel on Degraded and Marginal Lands

The recent assessments of the Indian government have identified 16% (> 50 m ha) of the geographical area as wasteland (Government of India 2010). Keeping in mind the 221 million poor in India, and the fact that 70% of poor in India are small marginal farmers and landless labourers (Srivastava 2005), it is essential that wasteland development programs are undertaken to generate the needed socioeconomic benefit for poor farmers and labourers. As a plant of the dry regions of Meso-America, Jatropha is suitable to grow on degraded drylands. Distributed by the Portuguese colonial power, Jatropha now grows in many African and South-Asian countries, and is well adapted to semi-arid tropical conditions. Jatropha is drought tolerant and can survive under 200 mm water per year. Its mechanism of leaf fall in dry spells increases the amount of organic matter in the soil, which makes Jatropha not only the one adapted to degraded lands, but the one rehabilitating them. Its dense root system stabilizes soil and arrests erosion. It produces fruits with a high content of non-edible oil that can be used for several purposes and is not browsed by animals. Thus, Jatropha can be a good candidate to rehabilitate the degraded lands mostly in possession of poor and marginal farmers and generate additional income for them. Grass et al. (2008) found that at crude prices above US $ 75 per barrel, Jatropha fuel production on India's wasteland starts to be economically viable.

To develop a strategy that serves both energy and food needs, work has been initiated recently for growing energy plants suitable for the degraded lands. According to a report of the committee on biofuels constituted by Planning Commission, Government of India (2003) out of a large number of oilseed tree species, Jatropha along with *Pongamia pinnata* would best suit the Indian conditions. For raising Jatropha, it is not necessary to sacrifice the land area that is already under cultivation of food and horticultural crops as Jatropha has the inherent ability to thrive on degraded and marginal lands. Jatropha is a fast growing crop, not browsed by cattle and goats with ability to withstand harsh climatic conditions. The National Mission on Biofuels in India has identified about 13.4 million ha for *J. curcas* (and *Pongamia pinnata*) plantations in immediate future and it covers poor, marginal, degraded, fallow, waste and other lands, such as along canals, roads, railway tracks, on farm and property bunds in the arid and semiarid areas. Once success is achieved on potential lands, it should be possible to include lands with low fertility soils, which can be brought under Jatropha plantation in an economically feasible manner to rehabilitate them. By adopting knowledge-based and pro-poor strategy, non-edible oil can be used for biodiesel production. Pro-poor bio-power strategy leads to a win-win-win situation that improves livelihoods, protect environment and allows the energy release from renewable sources.

Coherent National Policy on Biofuels

Biofuels are gaining importance ever since the prices of fossil fuel began skyrocketing due to the reduced supplies and growing concern with environmental pollution. Both developed and developing countries are formulating policies for a mandatory blending of bioethanol and biodiesel (produced from renewable sources) with fossil fuels, resulting in a huge demand for raw materials for producing biofuels.

Realizing the urgency, the Government of India has formulated and approved a National Policy on Biofuel in 2009 along with setting up of an empowered National Biofuel Coordination Committee, headed by the Prime Minister and a Biofuel Steering Committee headed by Cabinet Secretary. Under the approved policy, the country aims to rise blending of biofuels with gasoline and diesel to 20% by the year 2017 (Achten et al. 2010). The policy focuses on indigenous production of biodiesel in waste, degraded and other marginal lands. It incorporates the announcements on Minimum Support Price (MSP) with the provision of periodic revision for biodiesel oilseeds to provide fair price to the growers, which would be based on the actual cost of production of bioethanol. In case of biodiesel, the MSP could be linked to the prevailing retail diesel price. The National Biofuel Policy envisages that biofuels, namely, biodiesel and bioethanol may be brought under the ambit of "Declared Goods" by the Government to ensure unrestricted movement of biofuels within and outside the states. It is also stated in the Policy that no taxes and duty would be levied on biodiesel.

Biodiesel, A Convenient Energy Source with Good Fuel Properties

During the last few decades researchers tried many edible and non-edible oils in compression ignition for different utilities. Due to short supply, India can neither afford usage of edible oils as power source nor can afford to bring in agricultural lands under biofuels. Hence, the cultivation of non-edible vegetable oils on degraded and marginal lands is strategically propagated.

Biodiesel was among the first alternative fuels with bioethanol to really become known to the public. The advantage of biodiesel is that it can be used in existing vehicles with little or no modification required when used as blended. There are energy plants available that will produce a higher yield in kWh per area, but the simplicity of having a fuel that is fully compatible with present fuel and engine technology makes Jatropha biodiesel very attractive.

Jatropha biodiesel has good fuel properties, comparable to or even better than petroleum diesel (Rao et al. 2008). Its cetane number (an indication of its fuel burning efficiency) is 51–52 for biodiesel from Jatropha oil, which is higher than the cetane number of most petroleum diesels. It has 10% built-in oxygen content that helps it to burn completely. The esters of the long-chain fatty acids of biodiesel are excellent lubricants for the fuel injection system. It has a higher flash point than diesel, making it a safer fuel. Other advantages are the almost zero sulphur content and the reduced amount of carbon monoxide, unburned hydrocarbons and particulate matter in the exhaust. But there are a few technical issues that need to be resolved. Biodiesel has a high viscosity at low temperatures, leading to flow problems at these temperatures.

ICRISAT assessed the performance of the vehicles (8 TATA Mobile 207Di, 2 Nissan Diesel and 1 Toyota Qualis) being run since May 2007 on fuel blended (B10) with biodiesel (400 L received from Southern Online Bio Technologies Ltd). The observations and comments by automobile engineer from Farm and Engineering Services at ICRISAT were very encouraging. All vehicles put on fuel mixtures performed normally. There was no starting trouble or pickup problem in any vehicle. There was no abnormal smoke or other specific complaints from the users while driving the vehicle.

Refining Agronomic Practices for Realizing Higher Productivity

Optimizing Fertilizer Practices

Jatropha is well adapted to marginal lands, but it responds to fertilizer application. Nutrient management is one such aspect that may play a pivotal role in economic cultivation in marginal lands. Information available on nutrient requirement of Jatropha is scarce and particularly in wastelands where it is nil. The work to evaluate the effect of nitrogen and phosphorus on growth and productivity of four year-old Jatropha, planted on wastelands at ICRISAT, showed response to fertilizer application. In the on-station study, four-year-old Jatropha plantation recorded 1,290 kg ha^{-1} seed yield in the fertilized control plots (Table 16.1). The seed productivity varied from 1,320 to 1,610 kg ha^{-1} with the application of nitrogen and phosphorus fertilizers. The highest productivity was recorded at 80 kg N and 20 kg P_2O_5 ha^{-1}.

Table 16.1 Effects of nitrogen and phosphorus on seed yield of four-year-old Jatropha planted in wastelands at ICRISAT, India during 2008

Fertilizer/plant	Seed yield (kg ha^{-1})
Control	1,290
N (40) + P_2O_5 (10)	1,320
N (40) + P_2O_5 (20)	1,330
N (80) + P_2O_5 (10)	1,560
N (80) + P_2O_5 (20)	1,610

Source: Wani et al. (2012)

Growth Regulators

Jatropha is a monoecious shrub, where the flowers are unisexual, i.e., male and female flowers are produced in the same inflorescence. Inflorescences produce a central female flower surrounded by a group of male flowers. Generally, there are 1–5 female flowers and 25–90 male flowers per inflorescence with an average male to female flower ratio of 29:1.

Studies were conducted at ICRISAT during 2009 to evaluate the effect of growth regulators like naphthaleneacetic acid (NAA), gibberellic acid (GA), chlorocholine chloride (CCC) and ethrel on the male and flower ratio and yield of Jatropha planted in the year 2004. The results revealed that yields were in general low due to unfavourable weather, but application of either CCC or GA at 90 and 25 mg kg^{-1}, respectively, at the time of flower initiation can improve the flowering characteristics and crop yields.

Mycorrhizae Inoculation

Keeping in view the water and nutrient stress in marginal lands where Jatropha is supposed to grow, the effective absorptive root surface can be increased by inoculating roots with mycorrhizal fungi. Mycorrhizal fungi increases nutrient uptake not only by increasing the absorbing surface area of roots, but also through the release of powerful enzymes into the soil that dissolve hard-to-capture nutrients, such as organic nitrogen, phosphorus, iron and other tightly bound soil nutrients. This extraction process is particularly important in plant nutrition in marginal lands and explains why non-mycorrhizal plants require high levels of fertility to maintain their health. ICRISAT has raised Jatropha following mycorrhizal application to enhance growth and yield of seedlings. One gram of mycorrhizae may be placed below the seed at the time of sowing to enhance growth of the seedlings. Mycorrhized Jatropha seedlings showed higher plant height, stem girth and number of leaves compared to non-mycorrhized, when sampled three months after sowing (Table 16.2).

Table 16.2 Effects of mycorrhizal inoculation on growth of 3-month Jatropha seedlings in nursery at ICRISAT

Treatment	Plant height (cm)	Stem girth (cm)	Number of leaves
Inoculated	47	6.5	16
Non-inoculated	35	5.9	12

Source: Wani et al. (2006)

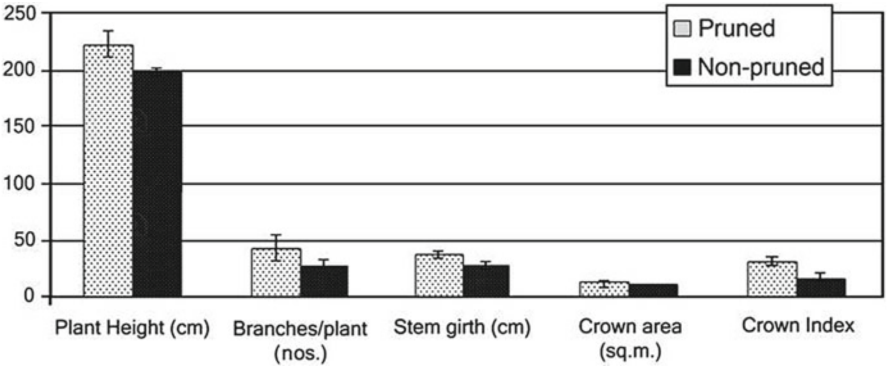

Fig. 16.1 Growth characteristics of Jatropha plants due to summer pruning during the 3rd year of establishment (Source Wani et al. 2009a)

Pruning and Irrigation

Jatropha produces flowers in cymose inflorescences with dichasial cyme pattern in new borne branches and hence, the number of new branchlets determines the number of inflorescences in Jatropha. Therefore, pruning is essential to increase the number of fruiting branchlets in Jatropha, which is carried out by nipping the terminal bud to induce secondary and tertiary branches.

A study was carried out to assess the effects of pruning on canopy characteristics of Jatropha in which half of the plants in the block plantation were pruned at 45 cm in the first year and 75 cm in the second year of growth during the dry season (February–March) when the plants are dormant and the rest half were grown without pruning. During the third year, the top one third of the secondary and tertiary branches of plants were nipped off under the pruning treatment. The effect of pruning was observed on plant height, stem girth at 10 cm above the ground, number of branches, crown area, and volume index during third year (Fig. 16.1). The results showed that pruning significantly ($p<0.05$) influenced plant height (224 cm), stem girth (36 cm), and crown index (29) compared to the non-pruned plants, where the plant height, stem girth and crown index were 197 cm, 27 cm, and 15, respectively. Similarly, the branches per plant were also more numerous (43) in the pruned when compared to the non-pruned (26) plants.

Similarly, Jatropha is well adapted to drought conditions, but shows profuse growth under irrigated conditions compared to no irrigation. As the fruits are borne on new branches in Jatropha, the enhanced growth and number of branches has direct relation to fruit and seed yields.

Water Requirement, Balance and Soil Conservation Under Jatropha cultivation

Soil moisture was monitored in the Jatropha plantation (seedlings planted in November 2004) at ICRISAT from November 2005 using a neutron probe. Weather was monitored at the ICRISAT agrometeorological observatory, Patancheru. Daily reference crop *evapotranspiration* (ETo) was computed following the FAO Penman-Monteith method (1998). Evapotranspiration requirements of Jatropha under ideal soil moisture conditions were estimated based on ETo and crop coefficients measured for different phenophases. Evapotranspiration values under actual field conditions of Jatropha plantation were estimated from soil moisture measurements using the standard water balance equation.

Monthly crop evapotranspiration (Fig. 16.2) values indicate that during April to June, ETo requirements are high due to atmospheric demands as well as the vegetative stage of plantation. However, this is the period in which the actual availability with respect to demand is low. During July to October, soil moisture status is sufficient to satisfy much of the ETo requirements and this period coincides with flowering and fruit set stage. During three years from 2005 to 2008, Jatropha used 75–90% of the rainfall received. Lower relative utilization (%) occurred when the rainfall distribution was erratic, though the rainfall amount was high. In the year 2008, rainfall till 30th

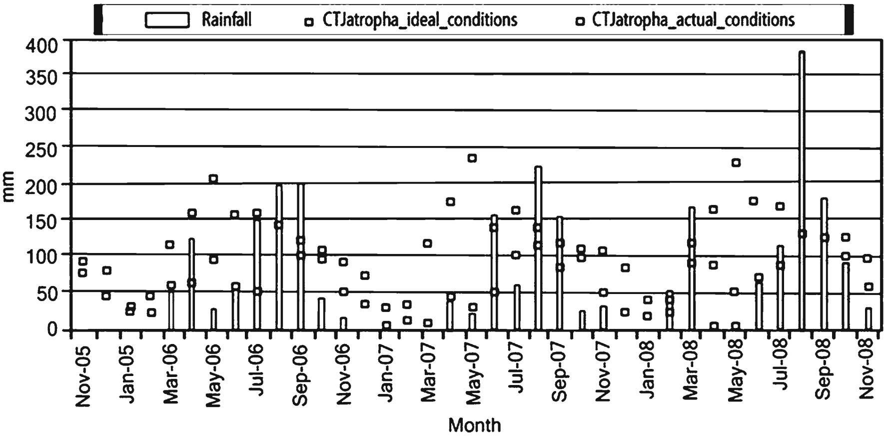

Fig. 16.2 Variation of rainfall and ETo in the Jatropha plantation at ICRISAT (Source Wani et al. 2009a)

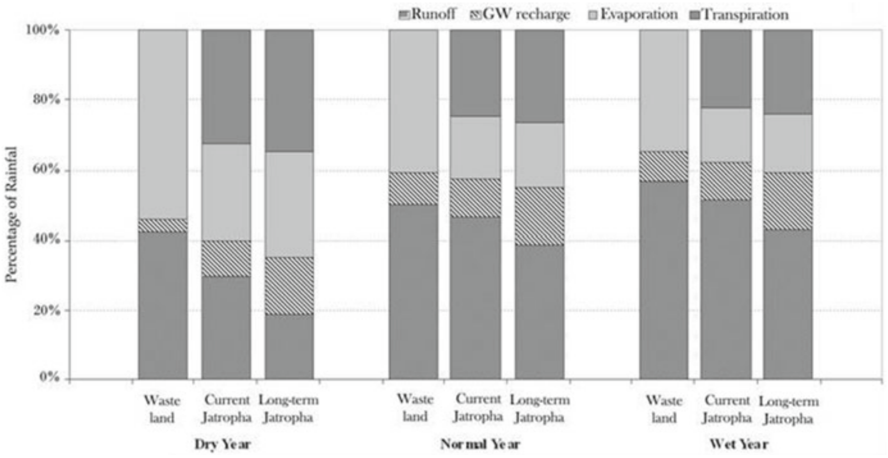

Fig. 16.3 Water balance components of different land management scenarios during dry, normal and wet years (data compiled from 2001 to 2010) (Source Garg et al. 2011)

November was 1,103 mm; however, total rainfall during June and July was only 190 mm compared to the normal 305 mm. The August rainfall was 382 mm compared to the normal 220 mm. There were eight days in the year 2008 with a rainfall of more than 50 mm and long periods of dry spells occurred in June and July. The total ETo use by Jatropha in the year 2008 till November was 820 mm, the highest in the last three years. If the rainfall distribution was good, Jatropha could have used even more water. The study indicated that contrary to the belief that Jatropha needs less water, under favourable soil moisture conditions, Jatropha could use large amounts of water for luxurious growth and high yield.

Combining ArcSWAT and HYDRUS1D modeling tools, water balance components of Jatropha plantation were studied in contrast to wastelands in Velchal, Rangareddy district of Andhra Pradesh, India (Garg et al. 2011). The data showed that under waste lands, 40–60% of the rainfall got lost as runoff, while it was reduced to 20–40% under long term Jatropha plantation (Fig. 16.3). Groundwater recharge doubled in *current* Jatropha and quadrupled in the *long-term* (current Jatropha for long period of time) Jatropha plantation. More than 50% of the non-productive evaporation transformed into productive transpiration in both current and long term Jatropha plantations. The results showed clearly that in wastelands where crop management is difficult, Jatropha might be a better option for conserving water and converting non-productive evaporation into productive transpiration

Cumulative soil loss recorded over a period of 10 years under Jatropha showed 50% reduction in total soil loss as compared to waste lands (Fig. 16.4). The study documents the importance of Jatropha in soil conservation and arresting further degradation.

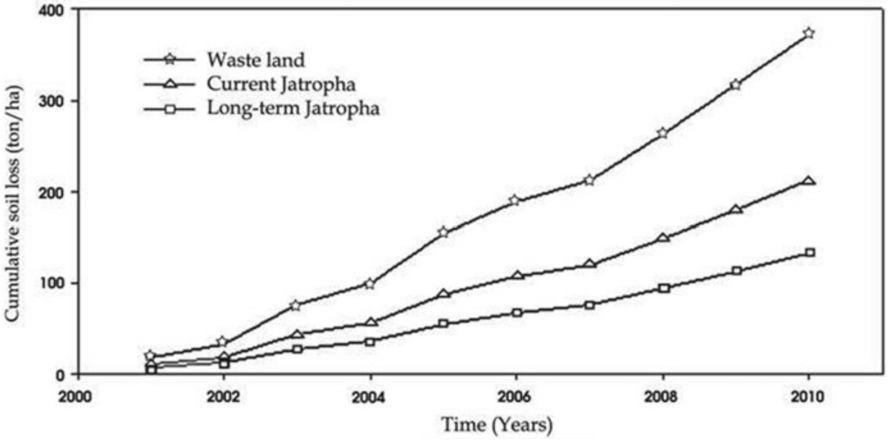

Fig. 16.4 Cumulative soil loss (t ha^{-1}) under different land management conditions (data from year 2001 to 2010) (Source: Garg et al. 2011)

Tapping Germplasm for Potential Productivity

In order to achieve full potential of biodiesel plantations with Jatropha, solution to the problem of low yield needs to be addressed to boost the large scale profitable cultivation. Genotypes influence yield potential, therefore the source of seed assumes greater significance. Genetic diversity in plant species is a gift to humankind as it forms the basis for selection and further improvement. It is desirable to select seed source for multiplication from known plant populations with favorable traits. However, comprehensive work on collection, characterization and evaluation of germplasm for growth, morphology, seed characteristics and yield traits is still in its infancy. The study conducted at ICRISAT (during 2008) on progeny trial evaluation comprising 99 Jatropha accessions collected from different agro-eco regions of India and planted during 2006 showed great variability in plant height (105–274 cm), collar diameter (5.1–18.9 cm), number of branches (9.7–66.3), crown area (0.5–6.3 m^2), volume index (8,056–85,708 cm^3), seed length (11.6–19.3 mm), seed width (9.5–11.7 mm), seed thickness (7.6–11.0 mm), 100-seed weight (38.9–67.1 g) and seed oil content (27.5–40.5). ICJC 06116 recorded the highest 100 seed weight of 67.1 g (Table 16.3). Accession ICJC 06004 recorded the highest plant height (274 cm) and ICJC 06087, the highest volume index (85,708 cm^3) and collar diameter (18.9 cm). The number of branches and crown area were the highest in ICJC 06115 (66.3) and ICJC 06010 (6.3 m^2), respectively. Highest seed length was seen in accession ICJC 06082 (19.3 cm) while accession ICJC 06055 showed the maximum seed width (11.7 cm) and thickness (11.0 cm). The highest oil content for seeds was 40.5% in accession ICJC06019. As a whole, 44% of the accessions have exhibited seed oil content in the range of 35.1–40%.

Table 16.3 Performance of selected *J. curcas* accessions for growth and seed traits at ICRISAT during 2008 (planted 2006)

Genotypes	Plant height (cm)	Collar diameter (cm)	Number of branches	Crown area (m^2)	Volume index (cm^3)	Seed length (mm)	Seed breadth (mm)	Seed thickness (mm)	100 seed weight (g)	Oil content (%)
ICJC 06004	274	16.0	52.1	5.3	76,077	17.9	10.9	9.1	53.9	31.2
ICJC 06010	226	15.0	54.5	6.3	51,563	17.9	10.9	8.6	51.2	37.8
ICJC 06019	228	12.8	41.4	2.4	38,653	16.6	11.4	10.7	52.3	40.5
ICJC 06055	135.9	5.8	14.9	0.8	8,972.8	16.7	11.7	11.0	46.1	34.9
ICJC 06066	168	6.4	23.4	0.8	10,433	16.9	10.6	7.6	54.8	32.1
ICJC 06082	207.5	14.0	32.4	1.5	41,756.3	19.3	10.3	9.3	53.3	35.0
ICJC 06087	233.2	18.9	51.5	3.5	85,708	18.2	11.3	9.0	56.8	37.3
ICJC 06091	202	18.3	51.0	3.4	68,345	17.6	11.5	10.3	64.3	39.1
ICJC 06115	213	14.7	66.3	3.2	48,761	17.3	11.4	10.7	66.7	34.8
ICJC 06116	205	17.6	61.9	3.5	64,976	19.1	11.5	8.9	67.1	29.4
ICJC 06117	201	15.3	62.2	3.7	50,474	17.7	11.6	10.8	58.2	34.7
ICJC 06120	198	10.6	48.5	2.3	23,850	18.7	11.0	8.6	66.6	34.4
Mean (of 99)	204	11.8	37.3	2.0	33,935	17.4	11.1	9.1	52.7	34.7
SEM	14.1	1.3	5.8	0.5	8,288.9	0.2	0.2	0.1	3.4	0.3
CD (5%)	43.6	3.9	17.8	1.3	25,664	0.6	0.5	0.4	11.2	0.8

Source: ICRISAT (2010)

Table 16.4 Marker attributes for AFLP combinations used at ICRISAT

Primer combination	PIC[a]	EMR[b]	MI[c]	RP[d]
E-ACT/M-CTT	0.34	95	32.30	46.82
E-ACA/M-CAA	0.20	88	17.60	23.11
E-ACA/M-CAT	0.25	77	19.25	26.21
E-AGG/M-CAG	0.25	101	25.25	34.81
E-AGG/M-CTA	0.24	119	28.56	39.17
E-ACG/M-CAA	0.24	117	28.08	38.84
E-AGC/M-CTA	0.30	83	24.90	37.53
Minimum	0.20	77	17.60	23.11
Maximum	0.34	119	32.30	46.82
Average	0.26	97	25.13	35.21

Source: Tatikonda et al. (2009)

[a] Polymorphism information content (PIC)

[b] Effective multiplex ratio (EMR)

[c] Marker index (MI)

[d] Resolving power (RP)

The objective for genetic improvement of Jatropha as a crop should aim at a larger proportion of female flowers or pistillate plants, high seed yield with high oil content, early maturity, resistance to pests and diseases, drought tolerance, reduced plant height and high natural ramification of branches. Jatropha is an often cross-pollinated crop and can be improved through mass selection, recurrent selection, mutation breeding, heterosis breeding and interspecific hybridization or biotechnological interventions to bring changes in the desired traits (Divakara et al. 2010).

Assessment of Genetic Variability Using Molecular Markers

Amplified fragment length polymorphism (AFLP) was employed to assess the diversity in the elite germplasm collection of *J. curcas* (Tatikonda et al. 2009). Forty eight accessions collected from six different states of India, were characterised with seven AFLP primer combinations that generated a total of 770 fragments with an average of 110 fragments per primer combination. A total of 680 (88%) fragments showed polymorphism in the germplasm analyzed, of which 59 (8.7%) fragments were unique (accession specific) and 108 (15.9%) fragments were rare (present in less than 10% accessions). In order to assess the discriminatory power of the seven primer combinations used, a variety of marker attributes like *polymorphism information content* (PIC), *marker index* (MI) and *resolving power* (RP) values were calculated (Table 16.4). Although the PIC values ranged from 0.20 (E-ACA/M-CAA) to 0.34 (E-ACT/M-CTT) with an average of 0.26 per primer pair and the MI values were observed in the range of 17.60 (E-ACA/M-CAA) to 32.30 (E-ACT/MCTT) with an average of 25.13 per primer pair, the RP was recognized the real attribute for AFLP to determine the discriminatory power of a primer pair. The RP values for different primer pairs varied from 23.11 (E-ACA/M-CAA) to 46.82 (E-ACT/M-CTT) with an average of 35.21.

Genotyping data obtained for all 680 polymorphic fragments were used to group the accessions analyzed using the UPGMA-phenogram and *principal component analysis* (PCA). Majority of groups obtained in phenogram and PCA contained accessions as per geographical locations. In general, accessions from Andhra Pradesh were found diverse as these were scattered in different groups, whereas accessions from Chhattisgarh showed occurrence of higher number of unique/rare fragments. Molecular diversity estimated in the present study combined with the datasets on other traits will be very useful for selecting the appropriate accessions for plant improvement through conventional as well as molecular breeding approaches.

Mass Multiplication

Seedling quality affects survival, growth and yield of the crop and therefore raising of healthy seedlings is important. Jatropha seedlings can be grown by two methods, namely bare root and container (polythene bag).

In the bare root method, nursery bed is prepared by mixing *farm yard manure* (FYM), soil and sand in equal parts. Soaked seeds are sown at a row spacing of 25 cm and plant to plant spacing of 5 cm. Plants that become ready for transplanting within 6 weeks after germination may be carefully uprooted from nursery beds, wrapped in wet gunny bag and transplanted within 24 h. Before transplanting it should be ensured that enough moisture is available in the pit receiving bare root seedlings.

Seedlings of Jatropha can be raised in poly bags (4″ × 7″, 150 gauge for three to four-month-old seedlings) filled with 2 kg medium comprising equal parts of soil, sand and FYM. Diammonium phosphate (DAP) may be added at 1.0 g per polybag. Good quality seeds having 80% germination should be sown at 1 seed per bag at 2–3 cm depth for getting higher germination success.

The study on evaluation of the effects of propagation techniques in Jatropha in Mali, showed more than 80% survival in plots planted with poly bag seedlings, followed by bare root cuttings as observed after 1 year of plantation. Planting of stem cuttings and direct sowing of seeds in the main field proved less effective and the survival rate was less than 20%.

Benefits of Intercropping in Jatropha During Gestation Period

Because Jatropha takes a minimum of 3–4 years for producing economic yields, the intercrops provide additional income to the farmers during the gestation period. The feasibility of growing drought tolerant field crops as intercrops with Jatropha

Table 16.5 Intercrop yields in strip cropping system with Jatropha at ICRISAT

Crop	Grain yield (t ha^{-1})		
	Year 2005–06	Year 2006–07	Year 2007–08
Sorghum	1.50	–	–
Pearl millet	1.15	1.2	–
Chickpea	1.01	–	–
Sunflower	0.98	–	–
Safflower	0.54	–	–
Soybean	1.06	–	0.51
Pigeonpea	–	0.56	0.62
Mung bean	–	–	0.29

Source: Wani et al. (2009b)

was studied until plantations were three-year-old on Vertisols at the ICRISAT farm, Patancheru, India. Intercrops, such as sorghum, pearl millet, pigeonpea, chickpea, sunflower, safflower, soybean and mung bean were successfully cultivated and evaluated in Jatropha plantations during rainy season and post-rainy seasons. Sorghum, pearl millet, soybean and chickpea yielded more than 1 t ha^{-1} (Table 16.5). The intercrops productivity in terms of grain yield varied from 0.29 t ha^{-1} in case of green gram (mung bean) to 1.5 t ha^{-1} in case of sorghum.

By-Product Deoiled Cake as Source of Nutrients in Crop Production

Deoiled cake is a by-product of oil extraction that contains all the macro and micronutrients and is an excellent organic fertilizer unlike inorganic fertilizers that supply only few nutrients. Jatropha seeds yield on an average 30% oil and around 70% by-product cake. The cake is suitable for fertilizing plantation or commercial crops. The studies at ICRISAT have indicated that Jatropha cake is relatively rich in nitrogen, phosphorus and sulphur (Table 16.6) compared to leaf and shoot parts.

The contribution of deoiled cake in crop production has been evaluated in maize and soybean crops (Osman et al. 2009; Wani et al. 2006). In an on-farm study by ICRISAT, a replacement of 50% basal N dose in maize through deoiled cake has promoted the maximum yield, which was around 4% more than pure inorganic fertilizers added at a rate of 120:60:40 kg NPK ha^{-1} (Table 16.7). Thus, Jatropha plants grown on degraded lands are useful not only for biofuel, but also for its nutrient rich deoiled cake in order to get higher crop yields with significant cuts on cost and use of chemical fertilizers.

Table 16.6 Chemical composition of deoiled cake from Coimbatore, Tamil Nadu analyzed at ICRISAT, Patancheru, India

Nutrients	Content in doiled cake of Jatropha
Nitrogen (%)	4.91
Phosphorous (%)	0.90
Potassium (%)	1.75
Calcium (%)	0.31
Magnesium (%)	0.68
Zinc (mg kg^{-1})	55
Iron (mg kg^{-1})	772
Copper (mg kg^{-1})	22
Manganese (mg kg^{-1})	85
Boron (mg kg^{-1})	20
Sulphur (mg kg^{-1})	2,433

Source: Wani et al. (2006)

Table 16.7 Effects of Jatropha deoiled cake application on grain yield of maize in Andhra Pradesh, India during 2007

Treatments	Plant height (cm)	Cob length (cm)	Cob diameter (cm)	DMP (kg ha^{-1})	Grain yield (kg ha^{-1})
Absolute control	220	13.44	7.77	11,424	6,640
50% of the basal dressing N (30 kg N ha^{-1}) through deoiled cake	217	17.38	8.04	15,491	9,560
100% of the basal dressing N (60 kg N ha^{-1}) through deoiled cake	228	16.94	8.02	14,193	8,490
100% of the basal dressing N (60 kg N ha^{-1}) through inorganic fertilizer^{-1}	226	16.82	8.12	15,498	9,200
LSD (5%)	NS	1.85	NS	1,240	796

Source: ICRISAT (2008)

C Sequestration and Land Rehabilitation

Carbon sequestration by Jatropha biofuel plantations not only mitigates global warming, but also helps in the reclamation of the degraded lands (Sreedevi et al. 2009; Wani et al. 2006; 2009b). Jatropha plants have a mechanism of drought avoidance by shedding their leaves during moisture stress periods to minimize the water requirement, which proves useful to exploit Jatropha in the rehabilitation of degraded lands. Pruned loppings also add C rich biomass to the degraded soil. In addition to deoiled cake (~500 kg C ha^{-1}), studies have revealed annual addition of around 1,000 kg C ha^{-1} to the soil under Jatropha by means of litter fall and pruned loppings (Table 16.8).

Table 16.8 Total C sequestered through Jatropha plantation as C returned to soil, biodiesel C replacement per year and live plant C

C through Jatropha plantation	Plant part involved	Organic C (kg ha^{-1})
C returned back to soil	Leaf fall	800[a]
	Pruned loppings	150 [a]
	Deoiled cake	495[b]
C replacement in fossil fuel	Jatropha oil	230 [b]
C in live plant	Shoots and roots	5,120

Source: Wani et al. (2012)

[a]Leaf and stem prunings added C every year

[b]Jatropha oil C (Fuel replacement) and deoiled cake added C from fourth year onwards every year

Table 16.9 Microbial population as influenced by Jatropha plantation at Velchal, Andhra Pradesh, India

Microbial parameters	Non-Jatropha plantation soil	Jatropha plantation soil	Coefficient of variation
Bacteria (cfu g^{-1}soil)	8×10^4	1×10^{5}[a]	54.6
Fungi (cfu g^{-1} soil)	1×10^3	2×10^{3}[a]	35.6
Actinomycetes (cfu g^{-1} soil)	8×10^2	8×10^{2}[a]	80.0

Source: Susanna (2009)

[a]Significant at 1%

In addition to C manure through leaf fall, pruned loppings and deoiled cake, the live plants sequester huge C quantities in its above ground and below ground biomass. Studies of Wani et al. (2012) revealed that a plantation at 2×2 m spacing accumulates 4.07 kg plant^{-1} as above ground shoots and 0.81 kg plant^{-1} as below ground roots. Similarly, a plantation at 2×3 m spacing accumulates 5.12 kg plant^{-1} as above ground shoots and 1.02 kg plant^{-1} as below ground roots. This translates to a C sequestration of 6,100 kg ha^{-1} at 2×2 m spacing (2,500 plants) and 5,120 kg ha^{-1} at 2×3 m spacing (1,667 plants). Such huge quantities of C sequestrated in plant biomass is a great ecosystem service we can have and these C credits can be traded, under the Kyoto protocol, with the countries or regions who are not able to manage their C credits (D'silva et al. 2004).

The annual additions of C through added leaves, loppings and decaying roots are enough to give the kick start to microbiological activities and nutrient dynamics. The microbial population is used as an indicator of soil health and thereby land productivity. The studies have revealed a higher level of microbial population complexity under Jatropha plantations (Table 16.9) as compared to non-Jatropha soil.

The falling leaves and loppings are recycle by microbial population, which releases and adds the nutrients to the soil and thereby increases soil fertility. A study from ICRISAT revealed the leaf fall of a three-year-old plant is ~2.6 fold that of a 1 year plant (Table 16.10). The falling leaves in a three-year-old plantation returned around 20 kg each of N and K and around 2 kg of P to the soil.

The cumulative C and nutrients added to soil through Jatropha biomass were documented by Wani et al. (2012). The *in situ* study carried out in a farm at Kothlapur

Table 16.10 Content and amounts of nutrients returned through fallen leaves during 2007 at ICRISAT, Patancheru

			Nutrient recycling by leaf litter					
Age of the plant	Fertilizer dose	Dry leaf (g/plant)	N (%)	P (%)	K (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
1-year- old	120 g Urea, 170 g SSP, 50 g gypsum	552.5	1.14	0.06	1.1	15.7	0.8	15.2
3-years- old	100 g Urea, 38 g SSP	1,451.1	0.86	0.08	0.95	20.8	2	23

Source: Wani et al. (2009c)

indicated a higher concentration of soil C and available P under the Jatropha plantation as compared to the adjacent uncultivated control grasslands (Fig. 16.5). The C in the surface (0–0.15 m) of soil under four-year-old Jatropha plantation increased by 19% as compared to the adjoining grasslands, which corresponds to about 2,500 kg ha^{-1} additional C sequestered by the plantation in four years. Carbon sequestration in these degraded infertile semi-arid tropical soils serves the dual purpose of reducing the atmospheric CO_2 concentration and increasing the soil organic carbon, which plays a crucial role in soil quality improvement and nutrient availability to plants (Srinivasa Rao et al. 2009). Similarly, available P in surface soil layer under Jatropha increased by as much as fivefold. A positive relationship between soil organic C and available P implies the role of increased organic matter in enhancing P and soil quality as a result of C sequestration (Wani et al. 2003).

Employment Generation and Social Mainstreaming

India is home of 22% of the world poor. Around 221 million poor in India do not have access to a consumption basket; a feature that is considered to define the poverty line. A programme that generates employment is therefore, particularly welcome. The biofuels sector has the potential to successfully rehabilitate the degraded lands and hence to improve the livelihoods of rural people by providing employment and additional sources of income (Wani et al. 2006). Biofuel plantation activity on commercial scale provides employment at village level through plantation, agronomic management, seed collection and through markets for fertilizer, pesticides, fuel and industrial raw material for soap/cosmetics, etc. Developing nations are looking towards biofuels to help reduce their spiraling foreign oil import costs, and to mitigate pollution and global warming. The drylands, often neglected compared to more favorable areas, can contribute importantly to a future powered by biofuels. In India, large tracts of degraded lands not suitable for arable cropping are in the possession of poor farmers. Our challenge and opportunity is to ensure that

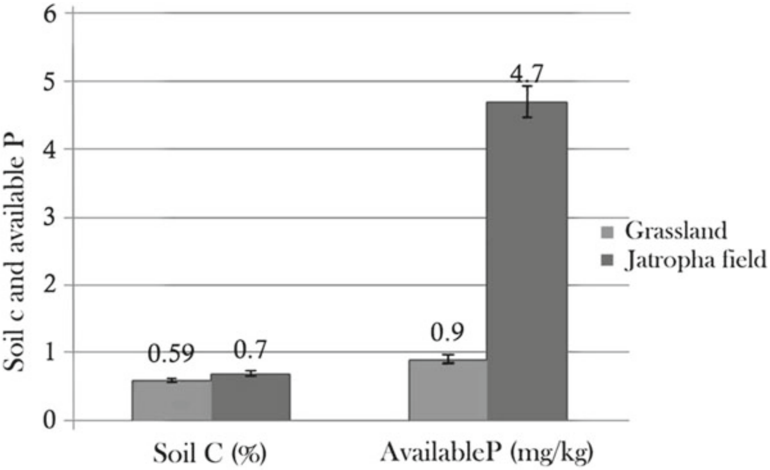

Fig. 16.5 Organic carbon and available P contents in surface (0.0–0.15 m) soil samples under Jatropha plantation in Kothlapur, Andhra Pradesh, India, 2009 (Source: Wani et al. 2011)

poor drylands will not be left behind. The carbon credits gained through switching from fossil fuels to biofuels can also be a source of income to the rural poor as these can be traded with the other developing or developed regions and countries.

A large part of India's population, mostly in rural areas, does not have access to energy services. There is an increasing gap between supply and demand, added with continuous deterioration in quality of power and a low level of access to electricity. Lack of access to affordable energy services among the rural poor seriously affects their chances of benefiting from economic development and improved living standards. Under such circumstances, decentralized power generation using biofuels is the need of the hour. Access to modern decentralized small-scale energy technologies, particularly renewable biofuels, are an important element for effective poverty alleviation policies. A program that develops energy from raw material grown in rural areas will go a long way in providing energy security to the rural people for their domestic use, farm production activities (e.g., irrigation, etc.) and engagement in livelihood activities (e.g., small processing mills) leading to improved incomes, better living and their social main streaming.

Insect Pests and Diseases

Jatropha has been believed to be less susceptible to various insect pests and other diseases merely based on few observations.

Insects, such as the leaf eating beetles, thrips, leaf hoppers, grass hoppers, caterpillars and leaf miner feed on the foliage. Shoot/stem borer and bark eating caterpillar damage the stem. Blue bugs and green stink bug suck on fruits while capsule

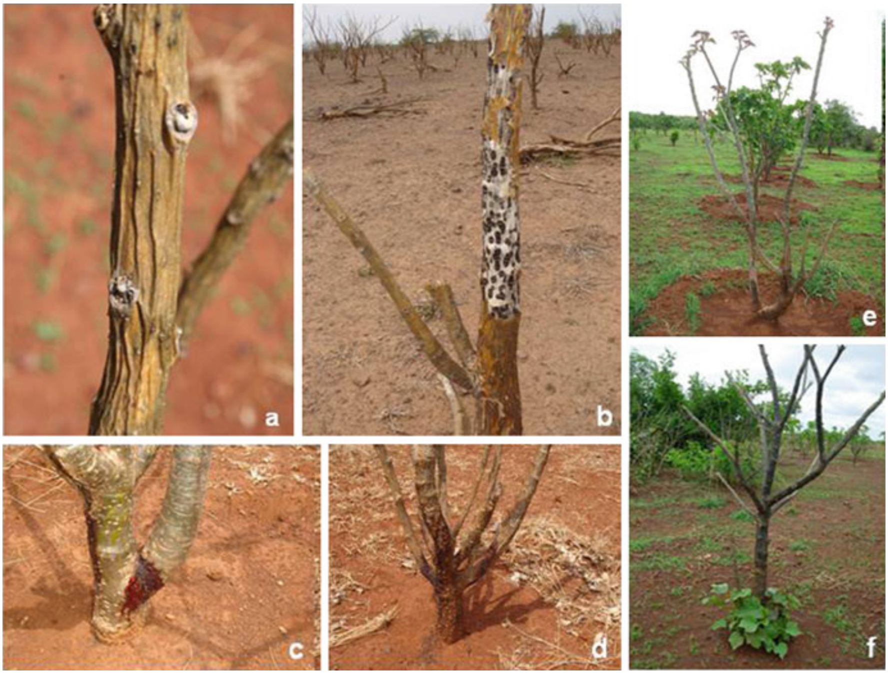

Fig. 16.6 (**a**) Shriveled appearance of black rot affected stems, (**b**) black lesions over the stem under the bark (*right*) caused by *Botryosphaeria dothidea,* (**c**) Exudation of reddish brown gummy substance from the late infected stem, (**d**) discoloration of the affected stem, (**e-f**) Initiation of new foliage from affected branches/ground after fungicide spraying in Velchal village plantation, Rangareddy district during July 2009 (Source: Srinivasa Rao et al. 2011)

borer damages the fruits (Wani et al. 2006). The pests may be controlled by spraying endosulfan at 3 ml per litre water or any other pesticide recommended for that particular pest. The galls are formed due to the attack of mites and can be controlled by spraying dicofol at 5 ml of water or wettable sulphur at 3 g per litre of water.

Diseases like root rot, damping off, powdery mildew and leaf spots, cassava mosaic virus are frequently reported when the crop is raised as plantations (Wani et al. 2006; Divakara et al. 2010). Black rot in Jatropha was observed during 2009 and 2010 in plantations in several states in India including Andhra Pradesh, Assam, Chattisgarh and Madhya Pradesh (Srinivasa Rao et al. 2011). Affected plants (Fig. 16.6a–f) showed drying along with shriveling, stem discoloration with sticky reddish brown exudation at the base of plants. Black lesions on the stem under bark and cambium layer were also observed. The symptoms spread to leaves and petioles as 1–3 mm diameter black spots as well as shriveling and gummosis of hard wood, finally leading to death of the infected plant. The causal fungus was identified as *Botryosphaeria dothidea*. Spraying affected plants at early stage of symptoms with bavistin (Carbendazim 50% WP) at the rate of 2 $g\,L^{-1}$ controlled symptom spread and led to recovery of plants with new leaf growth after the rains.

The studies on regional incidences of insect pests and diseases are necessary for the successful development of an effective package of viable agronomic practices.

Issues Confronting the Upscaling of Biodiesel Production

One of the main problems in getting the biodiesel programme running is the difficulty linked to initiating large-scale cultivation of Jatropha. The success of Jatropha oil for biodiesel production lies in the sustainable and economically viable production of seeds at field level. Farmers do not yet consider Jatropha cultivation remunerative due to the wrong perspective being adopted. Therefore, large-scale cultivation of Jatropha has been put into question and concerns have been raised regarding its success. Actually, the Jatropha cultivation in pilot studies on productive lands has been found to perform badly in terms of net returns when compared with cash crops, which caused serious setback to the program. It should be clear that Jatropha must be grown on lands where cash crops would hardy compete with it in order to warrant its comparative success. Further, diverting arable lands to cultivate such biofuel crops is not a viable proposition, as it will directly affect the food security of a country, which may have further deleterious consequences.

Among other issues challenging upscaling are low yields, lack of high yielding cultivars, high harvesting costs, diseases and pests in block plantations, water balance changes and off-site impacts. Further, in the absence of seed collection and oil extraction infrastructure, it will be difficult to convince entrepreneurs to install transesterification plants. Finally, there is the problem of co-product (glycerol) utilization. The co-product glycerol accounts for about 12% of the biodiesel produced and is of about 88% purity. If alternative means are not quickly found for utilizing glycerol, then its price will plummet due to excess supply.

The farmers are also reluctant in view of:

1. The lack of confidence due to the delay in notifying, publicizing and explaining the government biodiesel policy.
2. The absence of long-term purchase contracts prevents the buy-back arrangements or purchase centers for Jatropha.
3. The lack of availability of certified seeds with higher seed yield and oil content.
4. The lack of incentives and other benefits to farmers.

The government needs to produce measures that seriously address the farmers' concerns. Financial assistance should be given to organizations engaged in developing large-scale training programs for farmers. Subsidized promoting visits of progressive farmers to distant centers of excellence are required to enable them to witness success stories in biodiesel production and propagate their associated know-how.

Acknowledgements The support from National Oilseeds and Vegetable Oils Development, Government of India is duly acknowledged.

References

Achten WMJ, Almeida J, Fobelets V, Bolle E, Mathijs E, Singh VP et al (2010) Life cycle assessment of *Jatropha* biodiesel as transportation fuel in rural India. Appl Energ 87:3652–3660

D'Silva E, Wani SP, Nagnath B (2004) The making of new Powerguda: community empowerment and new technologies transform a problem village in Andhra Pradesh. Global theme on agroecosystems report No 11, ICRISAT, Patancheru, Andhra Pradesh, p 28

Divakara BN, Upadhyaya HD, Wani SP, Gowda CLL (2010) Biology and genetic improvement of *Jatropha curcas* L.: a review. Appl Energy 87:732–742

Garg KK, Karlberg L, Wani SP, Berndes G (2011) *Jatropha* production on watersheds in India: opportunities and trade-offs for soil and water management at the watershed scale. Biofuels Bioprod Biorefining 5:410–430

Government of India (2010) Wasteland Atlas of India, Government of India (GOI), Ministry of Rural Development, Department of Land Resources, New Delhi. Available from www.dolr.nic.in/wasteland_atlas.htm

Grass M, Zeller M, Wani SP, Sreedevi TK (2011) *Jatropha* fuel from India's wastelands: a financial analysis of different *Jatropha* production scenarios linked to possible crude oil price developments. J Fund Renew Energ Appl, Ashdin Publishing

ICRISAT (International Crops Research Institute for the Semi Arid Tropics) (2008) Supporting the Farmers' activities in the value-chain of biofuels, annual project report (October 2007–March 2008), ICRISAT, Patancheru

ICRISAT (International Crops Research Institute for the Semi Arid Tropics) (2010) Harnessing the potential of water-use efficient bio-energy crops for enhancing livelihood opportunities of smallholder farmers in Asia, Africa and Latin America, annual project report (2009–10), ICRISAT, Patancheru

IEA (International Energy Agency) (2007) World energy outlook 2007, China and India insights. International Energy Agency, Paris

Osman M, Wani SP, Balloli SS, Sreedevi TK, Srinivasa Rao Ch, D'Silva E (2009) *Pongamia* seed cake as a valuable source of plant nutrients for sustainable agriculture. Indian J Fert 2(25–6):29–31

Rao YVH, Voleti RS, Hariharan VS, Raju AVS (2008) *Jatropha* oil methyl ester and its blends used as an alternative fuel in diesel engine. Int J Agric Biol Eng 1:32–38

Sreedevi TK, Wani SP, Osman M, Tiwari S (2009) Rehabilitation of degraded lands in watersheds. Proceedings of the comprehensive assessment of watershed programs in India, 25–27 July 2007, ICRISAT, Patancheru, pp 205–220

Srinivasa Rao Ch, Vittal KPR, Venkateswarlu B, Wani SP, Sahrawat KL, Marimuthu S et al (2009) Carbon stocks in different soil types under diverse rainfed production systems in tropical India. Commun Soil Sci Plant Anal 40:2338–2356

Srinivasa Rao Ch, Kumari MP, Wani SP, Marimuthu S (2011) Occurrence of black rot in *Jatropha curcas* L. plantations in India caused by *Botryosphaeria dothidea*. Curr Sci 100(10):1547–1549

Srivastava P (2005) Poverty targeting in India. In: Weiss J (ed) Poverty targeting in Asia. Edward Eigar Publishing Limited, Cheltenham, pp 34–78

Susanna P (2009) Assessing environmental impacts of rehabilitated degraded uplands in watershed with *Jatropha* plantation. M.Sc. dissertation JNTU, Kukatpally, Hyderabad, ICRISAT, Patancheru

Tatikonda L, Wani SP, Kannan S, Beerelli N, Sreedevi TK, Hoisington DA et al (2009) AFLP-based molecular characterization of an elite germplasm collection on *Jatropha curcas* L., a biofuel plant. Plant Sci 76:505–513

Wani SP, Pathak P, Jangawad LS, Eswaran H, Singh P (2003) Improved management of vertisols in the semiarid tropics for increased productivity and soil carbon sequestration. Soil Use Manage 19:217–222

Wani SP, Osman M, D'Silva E, Sreedevi TK (2006) Improved livelihoods and environmental protection through biodiesel plantations in Asia. Asian Biotechnol Dev Rev 8:11–29

Wani SP, Marimuthu S, Sreedevi TK, Srinivasa Rao CH (2009a) Collection, evaluation of germplasm, standardization of agro-techniques and Pilot demonstration for *Jatropha curcas* L. in Rain Shadow Districts of Andhra Pradesh. Annual progress report 2008–09 of RSAD project, ICRISAT, Patancheru

Wani SP, Sreedevi TK, Marimuthu S, Kesava Rao AVR, Vineela C (2009b) Harnessing the potential of *Jatropha* and *Pongamia* plantations for improving livelihoods and rehabilitating degraded lands. In: Proceedings of 6th international Biofuels conference, Winrock International, New Delhi, 4–5 March 2009, pp 256–272

Wani SP, Sreedevi TK, Rockstrom J, Ramakrishna YS (2009c) Rain-fed agriculture—past trend and future prospects. In: Wani SP, Rockstrom J, Oweis T (eds) Rain-fed agriculture: unlocking the potential. Comprehensive assessment of water management in agriculture series. CAB International, Wallingford

Wani SP, Chander G, Sahrawat KL, Srinivasa Rao Ch, Raghavendra G, Susanna P et al (2012) Carbon sequestration and land rehabilitation through *Jatropha curcas* L. plantationin degraded lands. Agric Ecosyst Environ doi:10.1016/j.agee.2012.07.028