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RETROSPECT AND PROSPECTS OF EDIBLE OIL AND BIO-DIESEL IN PAKISTAN -- A REVIEW

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ABSTRACT:- Globally resources of petro-fuels are diminishing at a rapid rate. Efforts are underway to develop sources of bio-fuels. Out of the known sources of bio-fuels, Jatropha is one of the most promising option. The purpose of this study was to evaluate primarily the regional and global experiences to assess the potential of Jatropha farming in Pakistan and to conduct a comparative economic analysis of alternate feasible options e.g. production of oilseeds, which are also being imported in large quantities. Temporal analysis (1950-09) for edible oil consumption, production and imports is made. Projections for edible oil are worked out up to 2030. As there have been large variations in yield of Jatropha reported by various studies conducted in India and other countries, therefore most reliable data have been selected for analysis to assess the prospects in Pakistan. Comparative economic analysis is made in terms of oil contents, number of crops per year, yield and gross returns of oilseed crops and Jatropha. Analysis shows that increase in production of edible oil over the time is negligible against the large increase in requirement resulted in higher production gap being filled through imports. Projections made for edible oils illustrated that production gap is going to be wider, which is currently 1.86 million tonnes (mt) and projected to be 3.4 mt by 2030. Jatropha seed production analysis of water-yield functions revealed that yield varies from 1.1 t ha^{-1} in drought or dry spells to 12.75 t ha^{-1} with full irrigation in favorable environments. Benefit-cost analysis shows that break-even point can be achieved in fourth year of plantation of Jatropha. The projected consumption in Pakistan for petro-fuel for 2025 is 35.1 mt, which is almost double of the current consumption. Thus, the target projections for replacement of petro-fuel with bio-diesel will be 3.51 mt for which 3.5 mha of land is required, as Jatropha has to be grown in marginal areas with marginal yields. Comparative economic analysis shows that for sunflower and canola all conditions are favorable, as per frequency of crops, price and returns as oilseed get returns of 166% higher than Jatropha. Oil contents of sunflower and canola are higher than Jatropha. Analysis concludes that it is more feasible to grow oilseeds because in trade-off between food and fuel, food should win. Before launching commercial production of Jatropha in Pakistan key issues need to be addressed including maintaining the goal of food security, water scarcity, cost-effectivity, and feasibility of Jatropha in comparison with oilseeds, pulses, feed crops and fuel-wood plants.

Key Words: Jatropha; Edible Oil; Biodiesel; Farming Potential; Pakistan.

INTRODUCTION

Pakistan is facing a severe deficit of edible oils, and substantial amount of foreign exchange is being spent on the import of edible oils. The total annual edible oil requirement is 2.43 mt, out of which local production is 0.57 mt while 1.86 mt is being imported. Cottonseed contributes 51% of the domestic oil production while sunflower the second important crop is contributing about 32%, whereas canola and rapeseed/mustard contribute 17%. The gap between consumption and local production (1.86 mt) is bridged through import of edible oils worth $ 1.7 billion annually (GoP, 2009).

On the supply side, low growth of edible oils production can be attributed to:

(a) Oilseed crops compete with wheat which farmers prefer to grow as it is not only a staple food and subsistence crop but have higher economic value

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in term of marketable products i.e. grain and straw and other high value crops in terms of resources i.e. land and specifically water in favourable environments of the Indus basin;

b) High crop losses at the time of harvesting and during the oil extraction due to lack of appropriate technology;

c) Shortage of fresh water for profitable oilseed production; and

d) Neglect of effective policy support for production, import of edible oils and oilseed procurement prices.

On the demand side, higher demand of edible oil can be attributed to high income and low price elasticity (Chaudhary et al., 1998). Higher demand can also be the result of changes in the dietary habits of people as they have shifted towards foods consuming more vegetable oil. Edible oil prices in the neighboring countries are higher than Pakistan thus resulted in smuggling of imported edible oils to other countries (Ahmad and Hanif, 1986). This is a double loss to the country by spending foreign exchange on import and no gain to the government due to smuggling rather increased the demand for higher imports.

It is possible to increase area of oilseeds in different agro-ecological zones of Pakistan, where it can compete with other crops because oilseeds are having low water requirement. These potential areas include; Coastal areas; Barani areas; Rodkohi areas and Dobari lands in Sindh and Punjab provinces. In addition, there is potential for introducing high-yielding varieties of oilseeds based on ecology and water availability. For example, certain varieties of palm oil and coconuts can be grown in coastal areas, where freshwater is available. The plantation of coconut and oil palm along the coastal areas would not only help to produce edible oils, but it would also help to provide surface cover. Similarly, there is a scope for growing olive in the mountainous region (Chaudhary et al., 1998). Olive plants grow well in temperate climates of Balochistan, Gilgit Baltistan and *barani* areas.

Barani areas have the potential to produce oilseeds. There is a large contingent of oilseeds that proved to be promising including rapeseed/mustard, canola, groundnut, sunflower, safflower and sesame. Groundnut is an important oilseed crop having 33% oil contents. Groundnut requires light soils and due to this specific requirement, its cultivation is confined to sandy soils. Canola, a promising oilseed with high yield potential, can also be grown in *barani* areas having higher rainfall. It can be cultivated on all kinds of land except on saline soils and sandy lands. It requires about 3-4 irrigations during the growing season (Jiskani, 2001) or well distributed rainfall to meet crop water requirement. Canola yield is 0.96 t ha^{-1} against the potential of 3 t ha^{-1} (GoP, 2009). However yield of Canola has been fluctuating over the time. Maximum yield was 1.5 t ha^{-1} for 2002-03 (GoP, 2004). Its harvesting at optimum time is important because early harvesting can reduce seed quality and late harvesting can enhance shattering. Oil is upto 40% of seed weight (Weber et al., 1993). Similarly, in *barani* areas, most of the cultivable land is kept fallow, when monsoon rains are adequate to provide water for summer oilseed crops like soybeans. Experience of sunflower was not that rewarding due to heavy monsoon rains. In the Dobari lands of Sindh and Balochistan, safflower can also be grown as Dobari crop using residual moisture of harvested rice fields. Sunflower has gained higher popularity and acreage for boosting production of edible oils. It is a short duration crop (3-4 months), with higher yield potential (4 tha^{-1}) and wide range of growing seasons (autumn, spring and winter). It is a crop well adapted to semi-arid to arid environment with irrigation facility. Sunflower has potential to be grown in both irrigated and high rainfall *barani* areas where rainfall is well distributed.

On the other hands, bio-fuels (crop and wood-based raw materials such as molasses, rice husks, corn and wood waste, which are processed into fuel) have begun to look like an increasingly viable option. Pakistan needs continuous supply of cheap energy. In renewable energy field, Pakistan is using hydropower for energy needs successfully, whereas projects regarding solar and wind energy are in progress. Biomass, a renewable energy source, is gaining interest of many researchers because it produces similar type of fuel extracted from crude oil. Energy from biomass only depends upon the availability of cheap raw material. Biodiesel (produced by the reaction of vegetable oil and alcohol) can be used with same or with better performance in diesel engines. It is a clean fuel that causes less environmental pollution as compared to petro-fuels. High cost and discontinuous supply of vegetable oils is the main hurdle for its general acceptance. Bio-diesel is the possible reciprocal to petro-diesel or otherwise diesel engine will be useless after the depletion of petro-fuels (Khan and Dessouky, 2008). For developing countries, bio-fuels can reduce energy import bills as well as earn precious foreign exchange. However, reconfiguring the fuel economy to renewable sources is not without risks. Similarly, multinational corporations giving price incentives to farmers, to switch from growing food crops to bio-fuel crops, can threaten food security. The specific bio-fuel is ethanol extracted from molasses, a by-product of sugar while other indigenous raw materials, such as maize, rice, wood pulp and other forest residues are available in large quantities, they do not offer the same scope for value addition that sugarcane does. The potential for producing bio-fuels from corn, rice husks and wood waste exists but has not been tapped yet. Despite the potential advantages, progress in promoting bio-ethanol lacks policy impetus. The oil refining companies, in collusion with the Ministry of Petroleum, have managed to keep a lid on private sector involvement (SDPI, 2007).

Jatropha plant has originated in Central America and spread to other tropical and subtropical countries. It is mainly grown in Asia and Africa. Used mainly as a living fence to protect gardens and fields from animals. It is claimed that Jatropha is resistant to a high degree of aridity and as such does not compete with food crops in medium to high rainfall areas. The seeds contain 30-40% oil that can be easily expelled and processed to produce a high-quality bio-diesel fuel, usable in a standard diesel engine (PARC-PSO, 2008).

Primary claims favoring Jatropha over other crops are its non-food nature, reported ability to grow on marginal lands and need for limited rainfall. However, experiences across developing world have been quite varied reflecting complexities in local practices, soil, water and climatic factors (PARC-PSO, 2008). The study conducted by Pakistan State Oil used 24 irrigations during the first year which contradict that it can grow in marginal lands with limited rainfall. The question posed to PSO and PARC-Coastal Agricultural Research Station, Karachi (CARS) is that why not they grow Jatropha under non-irrigated conditions, when they claim that it can grow with limited rainfall. The situation was same at Arid Zone Research Institute (AZRI), Bahawalpur and AZRI, Umerkot where almost same number of irrigations was applied.

Jatropha is considered to be drought tolerant and can be grown on the marginal lands with no or minimum water requirements. Rainfall required for Jatropha is reported between 200mm and 500mm (Donizeth, 2008). Claims are being increasingly questioned as experiences in India, Pakistan and many other countries have shown that for optimum Jatropha, yield water is an essential input under arid environments.

As per Indian experience the seedlings require irrigation during the first 2-3 months of planting. The requirement of water is contingent upon local soil and climatic conditions. The critical stages of irrigation (viz., transplanting, dry spell during summer in first year of plantation for survival in rainfed areas, flowering to control sex switching and promote anther dehiscence) and frequency need to be worked out to economize water application. The appropriate mulching practice should be worked out. Any material locally used as mulch like newspaper will help to conserve moisture for establishment of saplings (Gour, 2006). The irrigation at fortnightly intervals is compulsory to ensure year round production of flowers and harvest of seeds (Singh et al., 2006). It confirms the work done by AZRI, Bahawalpur; AZRI, Umerkot and PSO, Karachi.

Highest potential yields of Jatropha in South Africa are likely to be obtained in the coastal areas of KwaZulu-Natal, where temperatures range from 17°C to 28°C during October-April and from 11°C to 25°C in the colder months (May-September). Annual rainfall is about 690 mm, falling throughout the year, Eastern Cape, inland, and eastern slopes of the Drakensberg Mountains in Mpumalanga, where yields of over 8 t ha^{-1} are achieved. At the other extreme, low yields of less than 2 t ha^{-1} are found in the northern parts of the country and along the south-eastern seaboard. The central interior is not at all suitable for Jatropha due to low rainfall and frost. The effective management of commercially planted species in terms of possible water resource impacts requires accurate information on generalized water use and bio-physical production characteristics relevant to areas having planting potential. With such information largely lacking in Jatropha, the Department of Water Affairs and Forestry, South Africa adopted a cautious approach and to propose that, until necessary information becomes available, the large-scale cultivation of Jatropha, as with other new species having similarly uncertain water requirement, be declared a Stream Flow Reduction Activity (WRC, 2008). Similarly in Nicaragua, Zimbabwe, Jatropha grows well in hot climate with rainfall of over 1000 mm. Experience in Zimbabwe has shown that high rainfall in the relatively cooler parts of the country does not encourage the same vigorous growth. However, in the low-rainfall areas, such as in the mid-Save region, Jatropha grows well, although comparative yields have not been established. Jatropha does not thrive in wetland conditions. The plant is undemanding in soil type and does not require tillage. In southern Africa, the best time for planting is in the warm season to avoid the cold season since the plants are sensitive to ground frost that may occur in the cold season (RFDFSIRDC, 1998).

The review of regional and global experiences indicated that Jatropha can be grown cost-effectively in hot climates having rainfall of over 1000 mm per annum. This is the requirement for Pakistan's arid lands for a plantation which requires water throughout the year. Important to note that best crop yields are expected in hotter climates and thus water requirement will be higher than cooler regions. But the yields are marginal in cooler regions having incidence of frost or semi-arid to arid climates having low and uncertain rainfall. The spate irrigation and *barani* areas where water is available and farmers have large land holdings certainly provide an opportunity for bio-diesel plantation. These areas are located in D.I. Khan, D.G. Khan, Sibi, Lasbela, Umerkot etc. However, feasibilty has to be developed. Areas should be frost free.

The specific objective of this study is to evaluate primarily the regional and global experiences to assess the potential of Jatropha farming in Pakistan and to conduct a comparative economic analysis of alternate feasible options e.g. production of oilseeds, which are also being imported in large quantities.

MATERIALS AND METHODS

The study methodology is largely based on the analysis of secondary data for edible oils and bio-fuel (Jatropha). Temporal analysis for 1950-09 was conducted for edible oils consumption, production and imports using secondary data. Analysis of actual and potential yields was conducted for oilseeds using actual crop yield in comparison with the potential yields. Furthermore, projections for 2010-30 are made for edible oils consumption, production and production gap using average growth rates during 1990 and 2008.

As Jatropha is still in the phase of experimentation, so inferences are made from India due to similarity of ecologies (climate, soil and water). Seed and oils yield of Jatropha are found from fifth year as yields are low from first year of plantation while economical yield starts from fifth year since its plantation using data available for different spacing of plants, fertile and poor soils and irrigated as well as *barani* lands. Analysis of water-yield function is based on yield data from India for five years since plantation. On *barani* lands Jatropha seed yields are analyzed under low, normal and high rainfall scenarios. Under irrigated conditions seed production scenarios for light, medium and full irrigation are analyzed providing all the inputs. Statistical significance is checked out for the data of water yield function using Analysis of Variance (ANOVA) method.

Benefit-cost analysis is made comparing Jatropha cultivation on poor soils under rainfed farming and on fertile soils with irrigation using field data from India. In poor soils, analysis includes cost of land preparation, planting of seedlings, and weeding/harvesting. There is no fertilizer and irrigation applied. On the other hand in the fertile soils it includes the cost of land preparation, planting of seedlings, FYM, irrigation, and weeding/harvesting for the first year of planting while cost for the subsequent years includes fertilizer, irrigation, weeding/harvesting. Analysis of yield and gross return is made on the yield obtained in third year when plant starts its harvestable yield . Using benefit-cost analysis break-even point was estimated.

Comparative economic analysis of oilseeds and Jatropha in terms of oil contents, number of crops per year, yield and gross returns are worked out. Potential seed yield and oil content are taken for analysis under low, medium and high yield scenarios. Data for seed production of Jatropha is based on Indian experience while data for oilseeds is provided by the Oilseeds Programme at NARC, Islamabad.

Total consumption of petro-diesel is projected for 2025 based on average growth rate of total diesel consumption from 1990-2009 and 10% of that projection is calculated as per Economic Coordination Committee (ECC) policy. Land requirement for Jatropha cultivation is calculated to make analysis of the ECC target by utilizing domestic resources.

RESULTS AND DISCUSSION

Trend Analysis of Total Consumption, Production and Imports of Edible Oils in Pakistan

Pakistan was self-reliant in edible oils at the time of independence and maintained this trend till 1950s. Total consumption of edible oil is taken as local production plus imports with the assumption that whatever is produced and imported in a year is consumed. It, however, started importing edible oils to supplement domestic production in late 1950s but it was on limited scale until 1970. Share of imports sharply increased in the second half of 1970s when the import of edible oil were about 50% of the total consumption as compared to 5% in 1970 and this increasing trend is being followed till now. Domestic production of edible oil is 23% of the total consumption while 77% is being imported. In mid 70s, the canal water supplies had increased due to the storage reservoirs of Mangla, Chashma and Tarbela which became operational in 1967, 1971 and 1976, respectively (Afzal, 1996). This increase in water availability resulted in the adoption of high delta crops (cotton, sugarcane, fruits and vegetables) and area under oilseeds and coarse grains was reduced. According to GoP (1972, 1983, 1998, 1998a, 2004, 2007 and 2009), consumption increased significantly with the passage of time but there is very slow growth of production. In 1970-71, oilseeds occupied nearly 3% of total cultivated area, which is 2.4% in 2008-09. There was a little improvement in edible oils production with the introduction of sunflower as it promises high yield and higher oil contents. Since the last 15 years, production has shown fluctuating trends mainly attributed to the fluctuation in yield of cotton (Figure 1).

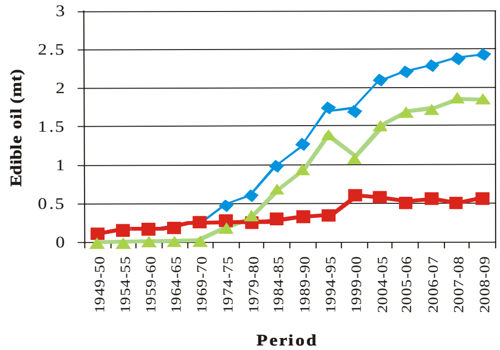

Figure 1. Historical trend of edible oil consumption (◆), production (■) and imports (▲) in Pakistan during 1949-2008

Actual and Potential Yield Analysis of Oilseeds in Pakistan

Actual yield of oilseeds (GoP, 2009) is in the range of 15-46% of potential yield (Muhammad, 1986). Although, safflower, sunflower and Canola are showing relatively good yield, they are still giving less than half of its potential yield. Lack of appropriate technology and inefficient harvesting and extraction machinery are the major factors contributing to low productivity and inefficient extraction of oil. Crop losses at the time of harvesting and during extraction of oil reduce production of edible oils. The low productivity of oilseeds is largely due to shortage of fresh water for profitable production (Figure 2), as they cannot compete with wheat.

Projected Edible Oil Requirement, Local Production and Production Gap

The burden due to the import of edible oils on the exchequer necessitates an increase in the domestic production of oilseeds. There is huge gap between consumption and domestic production of edible oils and if this trend continues, the gap would be further wider. According to GoP (2009), production gap is about 1.86 million tons. Total requirement of edible oils is projected with 3.76% growth rate and production is projected with 4.02% growth rate from 1990 to 2008. Total requirement of edible oil is projected at 5.36 mt by 2030 while projected level of production is 1.98 mt and the gap is 3.4 mt (Figure 3), within the current framework of policy and agricultural development in the country.

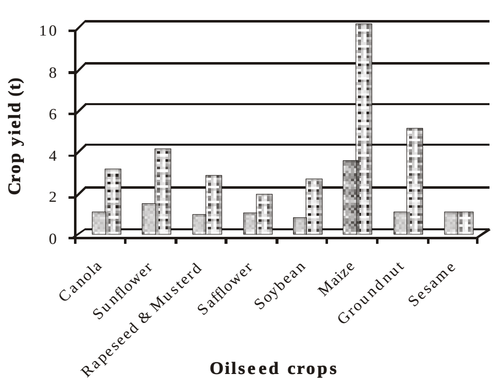

Figure 2. Actual (▤) vs potential (▦) yield of oil seeds in Pakistan

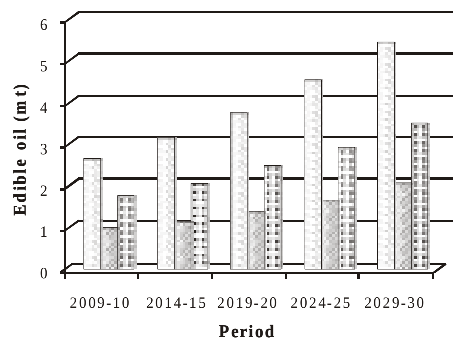

Figure 3. Projected edible oils requirement (□), production (▤) and production gap (▦) during 2009-2030

Situational Analysis of Jatropha Production in Pakistan

According to the US Energy Information Administration's 2006 International Energy Outlook, global consumption of marketed energy is projected to rise by 71% during 2003-30 (EIA, 2006). Given that energy demand is projected to keep rising and oil supplies are constrained, there has been intensive discussion about bio-fuels. Much of the discussion is projecting bio-fuels as a source of environment-friendly energy that would also be a boon to the farmers. Regarding Pakistan, the GoP policy states that 10% of the diesel and furnace oil consumed by Pakistan (i.e., 0.8 mt of diesel and 0.72 mt of furnace oil) be switched to bio-diesel, declining the country's import bill by US $ 1.00 billion. To achieve this target, land requirement will be around

0.43 mha (GoP, 2007). Some initiatives have been taken on experimental basis by various agencies to initiate production of Jatropha:

Pakistan State Oil (PSO) has planted 17,000 saplings of Jatropha in Sindh. To produce 10% blend of biodiesel, about 0.43 m ha of land is required for Jatropha plantation. PSO's ultimate goal is to significantly participate in blending 10% of country's total petro-diesel consumption (8 mt) with bio-diesel (PARC-PSO, 2008).

Small scale plantations of Jatropha were established on experimental basis on one acre land each at AZRI, Bahawalpur; AZRI Farm, Cholistan; AZRI, Umerkot and AZRI, D. I. Khan. The soil is clay-loam and sandy-clay. For the establishment phase, irrigations have been applied fortnightly from April to November and on monthly basis from December to March. The experimentation at AZRI, Bahawalpur also confirmed that 24 irrigations are required per annum during the first year of establishment(personal communication with Director AZRC, Quetta). The message is that irrigation is essential for growing Jatropha and irrigation input can be estimated at around 1200 mm per year. This confirms the results of Zimbabwe, India and other countries that over 1000 mm of rainfall is needed for optimal production of Jatropha (RFDFSIRDC, 1998).

Based on the initial progress, PARC has formally initiated a Project on bio-fuels covering Jatropha, Sukh Chain and Castor, where plantations are being expanded to larger area at AZRI, Bahawalpur; AZRI, Umerkot; AZRI, D. I. Khan and SARC, Karachi.

PARC and Kijani Energy (KE), a sustainable energy company of Canada, signed a MoU to focus on the development of large-scale cultivation of Jatropha in Pakistan. Objectives of the MoU was to undertake Jatropha cultivation on mass scale, to investigate its potential including cultivation on marginal lands with the consideration that such areas should not have been used for food production in the last five years, and educate farmers and industry with the benefits of growing and processing Jatropha (PARC News, 2009).

Pakistan has embarked on a bio-fuel driven model to address the need of energy and to evolve right protocols to plan and implement initiatives in a sustainable manner. This would mean factoring the impact of competition for other land uses, such as production of food or other crops at the planning stage. Feed stocks for bio-fuel remain at the core of any bio-fuels venture.

Jatropha Yield

Jatropha plants start yielding seeds within a year. It starts giving seed yield of 2-4 kg per plant from fifth year upto 40-50 years. Reports from the North East Hill region of India (Shankaran et al., 2003) showed the yield in different conditions: a) under dry land conditions, 1 t ha^{-1}; b) under hedge, 1 kg; and c) under irrigated conditions, 1.5 t ha^{-1}. Plantation is done at the onset of rains in July and extends up to the end of August. In September, the season becomes dry and cool which is unsuitable for plantation. The data provided is not adequate for developing any inferences for Pakistan as quantity and frequency of irrigation is not defined.

The strength of Jatropha so far recorded is the habit of desiccation tolerance. The bare rooted saplings once kept upright under shade survive even up to 90 days without loss of viability. The weakness of plant as a crop is low yielding nature and susceptibility towards frost. It could not survive above 1200 m where winter is severe and dry.

In another study, Jatropha yield ranges from 1-5 t ha^{-1}; whereas 2.5 t ha^{-1} is achievable and yield of 5 t ha^{-1} can be realized with optimal inputs. The yield increases till the sixth year and stabilize thereafter. It is mainly influenced by planting material and management practices. The Indian Council of Agricultural Research has identified first ever variety of Jatropha SDAU J1 (Chatrapati) for commercial cultivation for the semi-arid and arid regions of Gujrat and Rajisthan. It gives higher yield compared to other varieties. Farmers' average yield is 1.1 tha^{-1} under *barani* conditions. It is drought resistant and can be raised in areas with annual rainfall of 300-500 mm (Gour, 2006). However, the data provided does not indicate whether irrigations were applied, if not applied then how plant was established in very low rainfall regimes of 300-500 mm per annum.

Indian Council of Forestry Research and Education (ICFRE), Directorate of Oilseeds Research, Hyderabad reported that no promising varieties with either higher oil contents and/or responsive to higher inputs could be noticed in the country. If results so far available from field trials of research institutes (viz., Central Research Institute for Dryland Agriculture, Hyderabad; Gujrat Agricultural Institute, Dantiwada and Dr. Punjabrao Deshmukh Krishi Vidyapeeth, Akola) and private companies (Tree Oils Limited, Hyderabad) as well as the earlier experiences of a large number of Maharastra farmers, the average yields from available planting materials in dry lands are unlikely to exceed 1 t ha^{-1} $year^{-1}$ (Rao, 2006).

Minimum and maximum oil yield range given for irrigated area is 0.438-1.942 t ha^{-1} and for *barani* areas it varies from 0.175 to 0.971 t ha^{-1}. This is a clear indication that water is essential for having profitable yield. Spacing of 3mx3m is used for relatively fertile soils having water availability (1110 plants ha^{-1}), whereas spacing of 2mx2m (2500 plants ha^{-1}) is used where soil is relatively less fertile or poor soil and inputs like fertilizer and irrigation are not applied (Table 1). There is wide variability of yield within India. In this study frequency and quantity of supplemental irrigation is not defined for irrigated conditions. Further there is no mention that how plants were established under rainfed conditions.

Water Yield Functions of Jatropha

Review of Indian literature indicated that it is very difficult to estimate yield of Jatropha seed grown in varying climatic conditions, availability of water and age of plantation. Productivity is a function of water, nutrients, heat and age of the plantation. Many different methods of establishment, farming and harvesting are possible. Productivity can be enhanced with right balance of water, nutrients and crop management. According to CJP (2009) the yield varies largely with the age of plant and water availability. The seed yield varies from 1.0 to 12.5 t ha^{-1} after five years of plantation due to variation in rainfall and irrigation. In this study, rainfall and irrigation regimes are clearly defined and data are worth consideration for planning Jatropha plantations in Pakistan.

Jatropha Water-Yield Function under Barani Conditions in India

Throughout the literature there is a confusion regarding the yield of Jatropha, the variation has been reported by different agencies but the reason of such a wide variation was hardly explained.

Yield of Jatropha varies significantly with the age and highest yield under all the three rainfall regimes was achieved after fifth year in the order of 1.1, 2.0 and 2.75 t ha^{-1} respectively for low, normal and high rainfall regimes (Table 2). Results were significant at 1% level of probability. Further analysis of variance indicated that yield is also dependent on rainfall (i.e. 1.1-2.75 t ha^{-1}) at significance level of 1% of probability (Table 3).

The rainfall has direct influence on the productivity of Jatropha seed, as the yield reduced to almost one-third from high

Table 1. Economic yield of Jatropha (after 5th year)

	Minimum yield Spacing (2mx2m) - 2500 plant ha^{-1}			Maximum yield Spacing (3mx3m) - 1110 plant ha^{-1}		
	Yield/plant	Yield t ha^{-1}	Oil t ha^{-1}	Yield/plant	Yield t ha^{-1}	Oil t ha^{-1}
Rainfed	0.200 kg	0.5	0.175	2.5 kg	2.775	0.971
Irrigated	0.500 kg	1.25	0.438	5 kg	5.550	1.942

Table 2. Water yield functions of Jatropha under *barani* conditions for different planting period

	Jatropha seed yield (t ha^{-1}) under *barani* conditions		
Planting period (year)	Low rainfall	Normal rainfall	High rainfall
1	0.10	0.25	0.40
2	0.50	1.00	1.50
3	0.75	1.25	1.75
4	0.90	1.75	2.25
5	1.10	2.00	2.75

http://www.jatrophabiodiesel.org/jatrophaPlantation.php (CJP, 2009)

Table 3. Analysis of Variance (ANOVA) of Jatropha water yield function under *barani* conditions for different planting periods

Source of Variation	SS	df	MS	F	P-value	Fcrit
Rows	5.081667	4	1.270417	19.38334	0.000354	3.837853
Columns	2.817333	2	1.408667	21.49269	0.000606	4.45897
Error	0.524333	8	0.065542			
Total	8.423333	14				

rainfall to low rainfall regimes. This clearly shows that the statement normally given that it can be grown in marginal areas is not true for rainfall. Rainfall is a major factor in productivity as same level of nutrient was maintained in all the treatments.

Jatropha Water-Yield Functions under Irrigated Conditions in India

Yield of Jatropha varies significantly with the age and highest yield under all the three irrigation schedules was achieved after fifth year in the order of 5.25, 8.00, and 12.5 t ha^{-1} respectively for light, medium and full irrigation schedules (Table 4). Analysis of variance indicated that yield is critically dependent (Table 4) on water input (i.e. 5.25-12.5 t ha^{-1}) at significance level of 1% probability (Table 5).

This clearly shows that the statement normally given that it can be grown in marginal areas without irrigation is not true, because the irrigation input increased the productivity by five-fold. Thus, returns will be marginal without irrigation even in high rainfall regimes because of variability in occurrence and distribution

Table 4. Water-yield function of Jatropha under irrigated conditions for different planting

	Jatropha seed yield (t ha^{-1}) under irrigated conditions		
Planting period (year)	Light irrigation	Medium irrigation	Full irrigation
1	0.75	1.25	2.50
2	1.00	1.50	3.00
3	4.25	5.00	5.00
4	5.25	6.25	8.00
5	5.25	8.00	12.50

http://www.jatrophabiodiesel.org/jatrophaPlantation.php (CJP, 2009)

Table 5. Analysis of Variance (ANOVA) of Jatropha water yield function under irrigated conditions for different planting period

Source of variation	SS	df	MS	F	P-value	F crit
Rows	110.275	4	27.56875	16.45896	0.000629	3.837853
Columns	21.43333333	2	10.71667	6.39801	0.0219	4.45897
Error	13.4	8	1.675			
Total	145.1083333	14				

of rainfall. Variability in both spatial and temporal terms is very high in monsoonal and temperate climates. Thus, irrigation is the major factor in productivity as same level of nutrient was maintained. Higher rainfall can help to reduce irrigation input and thus reducing production cost.

Cost and Benefit Analysis

Among all the oil bearing crops, Jatropha has emerged as the focal point for the bio-fuel industry with rapid R&D investments flowing into its cultivation, processing and conversion into bio-diesel. With growing emphasis on the sustainability of the bio-fuels, there has been a pressure on regulatory and policy organizations to set in place sustainable models for Jatropha cultivation and use as a bio-fuel feedstock.

Cost and Benefit Analysis of Jatropha in India

Tamil Nadu Agriculture University (TNAU) reported that there are yield differentials of Jatropha seed from first year to the subsequent years. In the first year yield is nominal. In third year yield is harvestable. In fifth year economic yield is obtainable. Cost-benefit analysis is made based on the analysis of Jatropha cultivation on poor soils by NGO on fertile soils. In poor soil, 2mx1.5m spacing and in fertile soil 2mx3m spacing is used. In poor soil, it includes cost of land preparation, planting of seedlings and weeding/harvesting. There is no fertilizer and irrigation applied and it ends up in the Indian Rs. 10600 in the first year and in subsequent years only cost is of weeding/harvesting which is Rs. 2000 per year. In the fertile soil cost accounts for Rs. 17350 in the first year and Rs. 7500 in the subsequent years (Table 6). This includes the cost of land preparation, planting of seedlings, FYM, irrigation, and weeding/harvesting for the first year of planting while cost for the subsequent years includes fertilizer cost, irrigation, weeding/harvesting. Analysis of yield and return is made on the yield obtained in third year as Jatropha starts giving harvestable yield. Comparison of cost and return is made between the cultivation on poor soils under rainfed farming and fertile soils with irrigation. Jatropha on poor soils gives yield of 220kg oil ha^{-1} while it is 830kg oil ha^{-1} on fertile soils with irrigation.

Cultivation on Marginal Lands Gives Marginal Returns

Yield is taken from third year of plantation and projections of economics of Jatropha were made. Returns of Jatropha on poor/rainfed soils amounted to Rs. 6650 ha^{-1} while returns on Jatropha on fertile soils with irrigation are Rs. 24950 ha^{-1} (Table 7). There is variation in yield of Jatropha cultivated on marginal soils with no additional input comparative to the yield obtained from fertile soils with irrigation. This reveals the fact that hypothesis of cultivating Jatropha on marginal lands is not true for commercial scale activity.

The economics of growing Jatropha in fertile soils with irrigation is better than that of poor soils with no inputs provision. After the establishment of crop, cost in the

Table 6. Cultivation cost of Jatropha

Land	Poor soil of rainfed farming			Fertile soil with irrigation		
Spacing	2mx1.5m			2mx3m		
Density	3330 plants ha^{-1}			1670 plants ha^{-1}		
Year	I	II	III	I	II	III
Land preparation (Rs)	2000	0	0	1670	0	0
Planting of seedlings (Rs)	6600	0	0	8680	0	0
FYM (Rs)	0	0	0	1500	0	0
Fertilizer (Rs)	0	0	0	0	2000	2000
Irrigation (Rs)	0	0	0	3000	3000	3000
Weeding and Harvesting (Rs)	2000	2000	2000	2500	2500	2500
Total	10600	2000	2000	17350	7500	7500

Table 7. Yield and economic projections

Soil type	Poor soil under rainfed farming	Fertile soil with irrigation
Planting Density (m)	2 x 1.5	2x3
Population ha^{-1}	3330	1670
Seed yield (3rd year) (kg $plant^{-1}$)	0.200	1.5
Seed yield (kg ha^{-1})	670	2500
Oil Percentage -30 (kg)	220	830
Cake kg -70% kg	450	1670
Revenues @ Rs.20 kg^{-1} of oil (Rs)	4400	16600
Revenue @ Rs. 5 kg^{-1} of cake (Rs)	2250	8350
Gross total (Rs)	6650	24950

subsequent years is just the maintenance cost in both types of soils i.e., weeding cost in poor soil and irrigation, fertilizer and weeding in the fertile soil. If the crop starts giving the returns from third year then returns will be more than the cost in fourth year, and breakeven situation will be achieved. Subsequently maintenance cost will be the only cost which is almost constant but net returns will start increasing at increasing rate after fourth year as the yield increases after third year. The life of the plant is reported to be 50 years even if the life is shorter than 50 years suppose 30 years the net returns will keep on increasing till sustainable yield is obtained. After that yield may be constant so the returns will also be constant in nominal terms. It may be the case that yields start declining after a certain age in life (Figure 4).

Comparative Economics of Jatropha and Oilseed Crops

Economic analysis of Jatropha was conducted with other promising oilseeds including canola and sunflower. The economics of these two crops separately and collectively is higher than Jatropha. The analysis in terms of oil contents, numbers of crops per year, yield and gross returns was conducted. The comparative economics is based on three yield scenarios (low, medium and high) based on ecological and input conditions (Table 8).

The economic analysis revealed that:

- Sunflower and canola are the most profitable oilseeds. Two crops of sunflower are grown per annum. If water for Jatropha is diverted to these oilseed crops then at least 3 crops of oilseeds

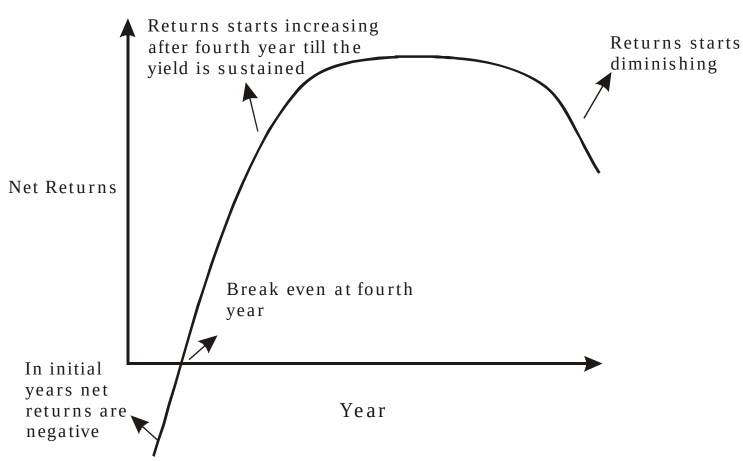

Figure 4. Net returns from Jatropha with respect to time

can be grown over a longer period of time. The opportunity cost of Jatropha is higher than that of the oilseeds.

- Two crops of oilseeds can be grown in a year with supplemental and life saving irrigation. On the other hand Jatropha yields are obtained once in a year. Though Jatropha starts yielding after first year of establishment but economic yield is obtained from fifth year. It is more economical to obtain two crops of oilseeds rather than growing Jatropha as mono-culture.
- Oil contents of sunflower and canola are higher than Jatropha. On the basis of data for annual seed production of Jatropha reported, it is obvious that it cannot compete with sunflower and canola in any scenario.
- If bio-diesel price is assumed same as of petro-diesel of Rs. 64 litre^{-1} and on the other hand edible oil price of 135 Rs. litre^{-1}, it is feasible to grow oilseeds than bio-diesel plants, as retail price of edible oil is double of petro-diesel. Because in the trade-off war between food and fuel, food should win.
- For sunflower and canola all conditions are favorable, as per frequency of crops, price and returns. Returns of canola and sunflower are higher than that of Jatropha. However, it can compete with

Table 8. Comparative economic analysis of Jatropha and oilseeds with minimum, medium and high yield scenario*

Crop	Seed production** (t ha^{-1})	Oil (%)	Crop year^{-1}	Seed (t ha^{-1} year^{-1})	Gross Returns^{+} (Rs.ha^{-1} year^{-1})
Low					
Sunflower	1	42	2	2	60000
Canola	0.5	40	2	1	40000
Jatropha (Av. for five years)$^{++}$	0.67	35	1	0.67	10050
Jatropha (Economic yield)	1.1	35	1	1.1	16500
Medium					
Sunflower	2	42	2	4	120000
Canola	2	40	2	4	160000
Jatropha (Av. for five years)	1.73	35	1	1.73	25950
Jatropha (Economic yield)	2.75	35	1	2.75	41250
High					
Sunflower	4	42	2	8	240000
Canola	3	40	2	6	240000
Jatropha (Av. for five years)	4^{+++}	35	1	4	60000
Jatropha (Economic yield)	6	35	1	6	90000

**Low and medium yield is of barani area with low and high rainfall respectively and high yield is of irrigated area with maximum irrigation.*

***Data for seed production of Jatropha from Table 2 for sunflower and from Oilseed Programme, NARC, Islamabad.*

+Price for canola ,sunflower and Jatropha seed is taken as Rs. 40 kg^{-1}, Rs.30 kg^{-1} and 15 kg^{-1}.

Total returns ha^{-1}= Quantity of the seed produced x price.

++As Jatropha start giving economic yield from 5th year and yield before that time is much behind teh potential so average annual yield for the first five years is taken.

+++Though maximum reported yield of Jatropha is 6.2 and 12.5 t ha^{-1} for average of first five years and fifth year respectively, but it is planted on marginal land using marginal water for irrigation the yield cannot exceed from 4 and 6 t ha^{-1}, respectively

oilseeds if its returns are increased by 166%.

- However, future scenario can be different when petro-fuel reserves will run short or may be depleted then demand of fuel will rise which will increase the prices of fuel and will result in improvement of economics on bio-diesel. However, currently Jatropha is not cost-effective as the returns are low and farmers are not ready to produce at that price.

Targets for 2025

The target by 2025 is to blend 10 % of bio-diesel with petro-diesel, which means that the import of petro-diesel will decline by 10%. The projected consumption of petro-diesel and blending of bio-diesel from 2008-09 to 2024-25 is projected (Table 9).

As per the target of the ECC, projections are made which shows that by 2008-09, country should be able to produce 1.66 mt of bio-fuel through different sources provided 10 % of the bio-fuel target. If 5 % of the total consumption of the diesel is considered then production target is to produce 0.833 mt. The projected consumption for petro-fuel for 2025 is 35.1 mt, almost double of the current consumption. The target projected for replacement of petro-fuel with bio-diesel will be 3.51 mt (10% of total consumption).

Land Requirement for Achieving Targets of Bio-Diesel by 2024-25

Land is not a limiting factor in Pakistan. But Jatropha should not hamper the food security. Although, it has the capability to grow in wastelands, but it should be raised in areas where food crops are neither grown nor can be grown. The projected scenarios for land requirement for the cultivation of Jatropha to meet the target of 10% replacement for 2024-25 to produce 3.5mt of bio-diesel are given in Table 10. Under medium yield projections, 1.0 tha^{-1} year of bio-fuel can be produced therefore, 3.5 mha are required in high rainfall areas to meet the target of 10% replacement by 2024-25. For high yield projections, 2.1 t ha^{-1} year^{-1} of bio-fuel can be produced therefore, 1.7 mha of land with irrigation facility are needed to meet the target of 10% replacement.

Key Issues

Ensuring sustainability standards for Jatropha projects in Pakistan would require a detailed assessment of economic, ecologi-

Table 9. Projected consumption of bio-fuels

Year	Present and projected consumption of petro-fuel	10% of petro-fuel be produced as a bio-diesel*
2008-09	16.6	1.66
2014-15	22.0	2.20
2019-20	27.8	2.78
2024-25	35.1	3.51

**As per the policy of the bio fuel from ECC, the 10% of the consumption of the diesel is also projected till 2025. Average growth rate of total diesel consumption from 1990-2008 has been taken as the base for the projection for the consumption in 2025.*

Table 10. Projected land requirements for Jatropha production in Pakistan to meet policy targets

Scenarios of target production of bio-fuels (%)	Projected production of bio-diesel (mt)	Required land (m ha)
25	0.9	0.87
50	1.8	1.75
75	2.6	2.62
100	3.5	3.50

cal and social dimensions at the planning and formulation stages of Projects. Jatropha is yet to deliver on its promises. Before going into the commercial production of Jatropha in Pakistan following issues need to be addressed by the policy makers:

Maintaining the Goal of Food Security

The first-most issue is to find the potential ecologies and suitable target areas for the Jatropha plantation economy without hampering the goal of food security. The bio-diesel crops will certainly compete for water and land resources where there is potential to grow food and feed crops and fuel wood plants. Therefore, the policy for production of bio-diesel crops must take into account all the factors related to the comparative advantages of Jatropha in relation to food and feed crops and fuel wood production.

Water Scarcity and Aridity

These are the two major issues confronting agriculture in the country. For optimal or profitable harvests over 1000 mm of water is needed per annum (from either rainfall or irrigation), irrespective of the type of soil or salinity level. Rather more water will be required for leaching fraction under poor quality waters (drainage or groundwater). Therefore, water must be considered as an essential element while conducting pilot projects and cost-effectivity must be linked with the amount of water used.

Cost-effectivity

Studies are needed for the cost-effectivity of Jatropha cultivation on longer terms comparing with other comparative advantages. One of the comparisons made in the study is with oilseeds because water requirement of canola and sunflower does not exceed Jatropha. Thus, water productivity and profitability of oilseeds is much higher than Jatropha. Therefore, cost effectivity must be given due consideration while conducting studies under forthcoming pilot projects. The questions to be addressed are: a) what is the opportunity cost of growing oilseeds for edible oils and Jatropha for bio-diesel? b) which one is lower in opportunity cost should be undertaken? and c) whose economics is best?

Feasibility of Bio-diesel Plantations

The basic question to be addressed that what is the feasibility of producing bio-diesel and/or edible oils in Pakistan. The other crops which can be added in the feasibility are: pulses; feed crops; and fuel wood plants. One of the schools of thought has developed passion for plants and it must also consider the factor that what is in favour of Pakistan on longer term. The question to be addressed by this school of thought is that when the country could not make headway in edible oils how it can be successful in bio-diesel oils. The issue is different how to make the feasibility economically, socially and environmentally viable. There is a need to make the climatic feasibility and right identification of the potential areas where Jatropha can be successfully grown. As it is sensitive to the frost so those areas where temperatures are low be avoided. Identification of potential areas for Jatropha not competing with food and feed crops and areas which are frost free. On the other hand, rainwater and floodwater harvesting must be encouraged to reduce the irrigation input and cost.

Small-holders

Jatropha does not appear very promising to small holders. They prioritize the food needs than anything else. Is it feasible for them to grow Jatropha even provided with subsidies? What incentives they have to grow Jatropha for substituting their land from food and feed crops to Jatropha? There are huge preliminary expenses for the cultivation of Jatropha, which appear to be a difficult for the small holders. Who are more in Pakistan than the large holders. In case of Jatropha, the returns are not immediate, though plants start yielding from first year but economical harvests can be obtained in 3rd-4th year, and small holders cannot wait for more than a year, as their food availability depends upon their farming.

Best Practices and Commercial Production

If it has to be adopted on the commercial scale then it cannot be grown on the marginal lands, experiences throughout the world show that yields on marginal lands would be marginal as well. To have best/ optimal yields best practices should be adopted in terms of production system, planting, harvesting and processing.

Marketing

There is lack of effective marketing and procurement system for the purchase of oilseeds in Pakistan. The government policies regarding oilseed production have been non-supportive in the favor of oilseed prices.

Recommendations

The following recommendation may be considered before going into the large scale production of Jatropha in Pakistan.

- Identify potential areas for Jatropha plantations not competing with food crops so that farmers are not deprived from earning livelihoods. Encourage other plants (i.e. Sukh Chain and Castor) having potential to grow in areas where conventional oilseeds cannot be grown without irrigation input.
- Encourage and support R&D Projects for bio-diesel to establish techno-economic viability of large scale plantations. The outcomes of local research should be widely disseminated amongst both potential growers and regulators. It is important for the government to engage with stakeholders and disseminate correct information so that informed decisions relating to cultivation of Jatropha can be made.
- Initiate twining and networking arrangements between the Ministry of Food and Agriculture; Ministry of Water and Power; Pakistan Agricultural Research Council; Alternate Energy Development Board, Islamabad provincial agriculture Departments and the Private sector for effective planning and implementation of projects.
- Establish procurement mechanism, system for support price of bio-diesel plants and incentives for large scale plantations.
- Encourage private sector to initiate large scale plantation through public and private partnerships.
- Avoid areas of low and variable rainfall, and susceptible to frost. Production in marginal areas should not be considered on commercial scale.
- Conduct feasibility study for the identification of areas where land and poor quality water resources are available especially water for the profitable farming of Jatropha/Sukh Chain/Castor.

LITERATURE CITED

Afzal, M. 1996. Managing Water Resources for Environmentally Sustainable Irrigated Agriculture in Pakistan, Pakistan Development Review, 35(4): 977-988.

Ahmad, M. and Hanif, M. 1985. Policy for increasing edible oil production in Pakistan. Paper presented in National Seminar on Oilseed Research and Development in Pakistan PARC:Islamabad May 7-9.

Chaudhary, M.G. Mahmood, A. and Chaudhary, G.M. 1998. Pakistan's edible oil needs and prospects for self sufficiency. Pakistan Development Review, 37(4): 205-216.

CJP. 2009. The Global Authority on Non-food Bio-diesel Crops/ Center for Jatropha Promotion, Rajasthan, India.

Donizeth, J. D. 2008. India's Policy on Jatropha-based Biofuels: Between hopes and disillusionment, Focus on the Global South- India.

EIA U.S. 2006. Strong Growth in World Energy Demand is Projected Through 2030. Report of U.S. Energy Information Administration, U.S. Department of Energy, Washington DC, June 20.

GoP. 2009. Agricultural Statistics of Pakistan, Government of Pakistan, Islamabad.

GoP. 2007. Vision 2030, Planning Commission, Government of Pakistan, Islamabad.

GoP. 2004. Agricultural Statistics of Pakistan, Government of Pakistan, Islamabad.

GoP. 1998. Agricultural Statistics of Pakistan, Government of Pakistan, Islamabad.

GoP. 1998a. Economic Survey of Pakistan, Government of Pakistan, Islamabad.

GoP. 1983. Economic Survey of Pakistan. Government of Pakistan, Islamabad.

GoP. 1972. 25 Years of Pakistan in Statistics. Government of Pakistan, Islamabad.

Gour, V.K. 2006. Production practices including post harvest management of *Jatropha curcas*, Department of Plant Breeding and Genetics Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur. Paper presented at the Conference Rashtrapati Nilayam, Bolaram, Hyderabad on June 9-10.

Jiskani, M. 2001. Need to cultivate crops on the availability of irrigation water. Pakistan and Gulf Economist, April 2-8.

Khan, N.A. and Dessouky, H. 2008. Prospect of biodiesel in Pakistan. Renewable and Sustainable Energy Review, 13 (6-7): 1576-1583.

Khan, S.R. 2007. Viewing biofuel (ethanol) prospects in Pakistan through a sustainable Department Research and News Bulletin. 14, (3). Sustainable Development Policy Institute, Islamabad, Pakistan.

Muhammad, A. 1986. Keynote address, at National Seminar on Oilseed Research and Development in Pakistan PARC, Islamabad. May 7-9.

PARC News 2009. MoU signed for cultivation of Jatropha seeds, 27 (2): 1, PARC, Islamabad.

PARC-PSO. 2008. *Jatropha curcas* L. Cultivation Experience in Karachi, Pakistan, Pakistan Agricultural Research Council, Islamabad and Pakistan State Oil, Karachi.

Rao, V.R. 2006. The Jatropha Hype: Promise and Performance. Paper presented at Biodiesel Conference towards Energy Independence – Focus on Jatropha Rashtrapati Nilayam, Bolaram, and Hyderabad, India. June 9-10 2006.

RFDFSIRDC. 1998. The potential of *Jatropha curcas* in Rural Development and Environment Protection an Exploration workshop. The Rockefeller Foundation and Scientific & Industrial Research & Development Centre, Harare, Zimbabwe. May 13-15.

Shankaran, M. Data, M. Singh, N.P. and Chandra S. 2003. Jatropha: A boon to wastelands. Agrobios Newsl. 2(7):53.

Singh, L. Bargali, S.S. and Swamy, S.L. 2006. Production Practices and Post – Harvest Management in Jatropha, Production. Paper presented at Biodiesel Conference towards Energy Independence – Focus on Jatropha Rashtrapati Nilayam, Bolaram, Hyderabad, India. June 9-10 2006.

Weber, J.A. Myers, R.L. and Minor, H.C. 1993. Canola: A Promising Oilseed. Department of Agronomy, University of Missouri, Kansas City.

WRC. 2008. *Jatropha curcas*: Measuring the Impact of Large-scale Planting on Water Resources. Water Research Commission, South Africa.

http://www.tnau.ac.in/tech/swc/jatropha.pdf.

http://www.jatrophabiodiesel.org/jatrophaPlantation.php.