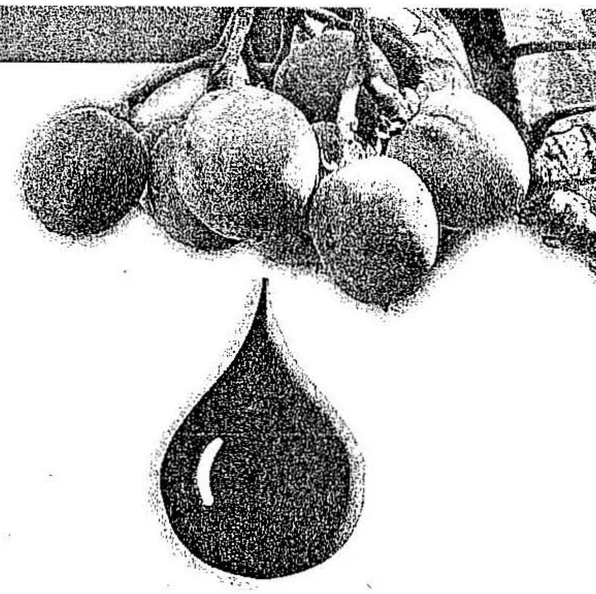

6th International Biofuels Conference

March 4-5, 2009

Hotel Le Meridien, New Delhi, India

CONFERENCE PROCEEDINGS

WINROCK INTERNATIONAL INDIA

788, Udyog Vihar, Phase V, Gurgaon - 122 001, India
Tel: 91-124-430 3868; Fax: 91-124-430 3862; Email: wii@winrockindia.org
Web: www.winrockindia.org

Registered Office: S-212, IInd Floor, Panchsheel Park, New Delhi - 110 017, India
Tel: 91-11-2601 3869; Telefax: 91-11-2601 3876

Harnessing the Potential of Jatropha and Pongamia Plantations for Improving Livelihoods and Rehabilitating Degraded Lands

Suhas P Wani[1], TK Sreedevi, S Marimuthu, AVR Kesava Rao and C Vineela

[1]Principal Scientist (Watersheds), International Crops Research Institute for the Semi Arid Tropics, (ICRISAT), Andhra Pradesh
Email: s.wani@cgiar.org

ABSTRACT

Current increase in demand of knowledge for alternative sources to fossil fuel has triggered lot of interest in use of non-edible oils as green knowledge source in developed and developing countries. ICRISAT is adopting pro-poor bio-fuel strategy to benefit vulnerable sections of the society through development of degraded common property resources and individual lands which are not suitable for food production by adopting consortium approach. Research and development options for harnessing the potential of Jatropha and Pongamia are undertaken to increase productivity of Jatropha and Pongamia plantations. Large variability in the accessions of Jatropha and Pongamia was observed for total oil content varying from 27.4% to 40.6% in case of Jatropha and from 21 to 41 % in case of Pongamia. These accessions are evaluated for different agronomic characters along with yield potential under rain-fed conditions at ICRISAT, Patancheru, India. Application of nitrogen and phosphorus at different levels indicated that during the 4^{th} year harvest index (pod to seed ratio) varied from 53-56% with different fertilizer treatment. The plant yield of *Jatropha* within an accession with 3x2 spacing varied upto 1.4 to 1.6 kg ha per plant (2.3 to 2.7 t ha^{-1} under rainfed conditions).

Water use efficiency of three years old Jatropha plantations indicated that evapo-transpiration demand under no moisture stress for Jatropha varied from 1150–1350 mm per year. Under the semi-arid tropical conditions Jatropha is able to use water relatively 40-57% of non-stress situation. Intercropping with Jatropha and Pongamia plantations is feasible and even during 4^{th} year in pruned Jatropha plantations with yield of different crops varying from 0.29 t ha^{-1} in case of green gram to 1.5 t ha^{-1} for sorghum. Intercrops like sorghum, pearl millet, pigeon pea, soybean, *mung* bean, chickpea, sunflower, safflower with Jatropha and pearl millet and pigeon pea with Pongamia could be successfully grown. An additional income of Rs.5,000 to Rs.16,000 per ha can be obtained on low-quality (but reasonably able to support crop growth) soil.

Nutrient budgeting approach can be used successfully to work out nutrients requirement needed to achieve targeted yields in crop like Jatropha. Fallen leaves quantity and nutrient content of Jatropha varied with plant age and fertility treatment and contained 9500 mg N kg^{-1} which is lowest amongst different plant parts such as shoots and seeds as well as deoiled seed cake. One year plantation returned 16 kg N ha^{-1} and three-year plantation returned 21 kg N ha^{-1} through fallen leaves. The fallen leaves also added 1000 kg ha^{-1} organic C to soil in addition to carbon fixed in seeds which will replace fossil fuel C. De-oiled seed cake after extracting necessary oil can be used as plant nutrient source on the farmers' fields. Benefits of oil seed cake application in terms of increased yields of maize, cotton and other crops were higher than N applied through mineral fertilizer source.

Introduction

In the 21st century, the world is facing multiple challenges with the ever-growing population and the increasing number of poor people. At the same time issues of food and energy security are haunting developed as well as developing countries worldwide, largely because of the increased uncertainties to meet the growing demand for food and fuel because of the changes affecting availability of food and fossil fuel due to political uncertainties, global warming and the associated climate change, and increasing awareness about the need for environmental protection.

Global demand for biofuels is increasing largely due to the policy decisions made in the USA and Europe to enhance use of biofuels to meet the targets for reducing the carbon emissions. Developing countries like India and Brazil are also in the race for biofuel production to meet their local demands and minimize C emissions. India is projected to become third largest consumer of transportation fuel in 2020 after USA and China. Recent statistics by Planning Commission of India, revealed that two wheeler ownership in cities will increase from 102 to 393 per 1000 people in the next 20 years, while the number of cars would increase from 14 to 48 per 1000. Hence oil import will continue to be an enormous burden on India's budget. According to a recent study by British Petroleum, oil export from Middle East to Asian countries accounts for 68% of the total export and merely 32% to Europe, Africa and American countries. It is estimated by the International Energy Agency (IEA) that increasing populations along with the 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 up to 45% of this increase. For India, one driver behind the growing demand 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). As oil is and will remain the main source for transport energy in near future, India's crude oil import dependence will increase from today's 70% to 90% in 2030. Therefore India could become third largest oil importer after the U.S. and China in 2024. The fact that diesel "makes up almost 70% of the oil used in Indian road transport" and that "the share of transport in final energy demand in India doubles from 10 % in 2005 to 20% in 2030" leads to the growing interest in developing a domestic biofuel industry in India. The Indian Government regards biofuel as suitable option for augmenting future energy demand. This has resulted in framing policies to use biofuel in the transportation sector.

Along with the growing interest in India for increasing biofuel production country has a major challenge to achieve food security for its growing population. Food demand is growing to increase by hundred per cent by 2050 and its arable land and available water resources will be shrinking due to competitive demands from other sectors. As the country is short of edible oil, there is no question of using edible oil as a source of biofuel. With increasing demand of water and land resources for food production and possible adverse impacts of the climate change on water availability and increased occurrence of droughts (IPCC 2007), the issue of biofuel production needs careful and well thought strategy in India. It has to be a win-win-win situation approach to produce biofuel, particularly biodiesel, without competing with land and water resources that are much needed for food production, while developing wastelands not suitable for crop production, and enhancing rainwater use efficiency and creating livelihood opportunities for the rural poor (Wani et *al.* 2007).

Pro-poor Biopower Strategy

To find ways to empower the dryland poor to benefit from, rather than be marginalized by, the bio-energy revolution, ICRISAT has launched a global BioPower Initiative (ICRISAT, 2007). It focuses on biomass sources and approaches that do not compete with, and in fact could well enhance food production by attracting greater investments that boost both food and biofuel productivity.

BioPower will seek approaches that forge a path out of poverty for dryland residents. It will enhance local bio-energy systems that build capacities and skills to generate bio-energy surpluses and to provide related goods and services. Such surpluses, goods and services will raise incomes by connecting the poor to commercial supply chains on fair terms. BioPower strategy takes a broader bio-energy systems perspective than just biofuels. Energy is essential for economic growth and escape from poverty. A broader bio-energy perspective will include the wider range of energy needs of the poor, especially their own household and community needs, as well as income-earning opportunities. This includes village bio-energy generation for heat, electricity, light and other needs; the recycling of bio-wastes for energy; social, institutional and economic dimensions of bio-energy, environmental impacts, sustainability and other important issues.

ICRISAT's BioPower Strategy, in short is to make the bio-energy opportunity work for the dryland poor instead of against them. The three main thrusts of BioPower are to increase rural bio-energy self-reliance and income, alleviate poverty through pro-poor biofuel markets and sharing the wealth through bio-energy knowledge.

Non-edible Oil Sources for Biodiesel

In countries like India, non-edible oil trees or plants which can be grown under rain-fed conditions, that too on low quality lands which are not suitable for growing food crops, are to be considered. The Planning Commission of India refers Jatropha *curcas* and Pongamia *pinnata* as promising candidates for biodiesel program due to its multiple benefits and wide adaptability. Jatropha and Pongamia being highly drought tolerant and well suited to semi-arid conditions are the most potential candidates for biodiesel production. Jatropha has liking to well-drained soils and is susceptible to collar rot disease in high rainfall humid areas or excessive irrigation or to water-logging; while Pongamia can tolerate water-logging, saline and alkaline conditions. Both the species are suitable for growing in low-quality lands in the semi-arid tropics as they are not browsed by livestock (Wani *et al.*, 2007). Straight vegetable oils from *Jatropha* and *Pongamia* are also used directly in high rpm diesel engines for power generation as well as pumping water (D'Silva *et al.*, 2004). The use of blended fossil fuels with bio-fuels results in substantial reduction of un-burnt hydrocarbons by about 30%, carbon monoxide by about 20% and particulate matters by about 25%. Moreover, sulphur content in the emissions from the use of blended fuels is almost negligible (Francis *et al.*, 2005). Detailed characteristics of both the plant species are described earlier (Wani et *al.*, 2007). Neem *Azadrichata indica* oil is used in Asia for pest control and straight vegetable oil from neem is currently tested as an energy source in Niger for running diesel engines (ICRISAT 2006). These crops can not only meet the oil demand for biofuel production but can also green the wastelands in drought-prone areas without sacrificing the food and fodder security and improve the livelihoods of rural poor (Wani *et al.*, 2006a&b)

The vast demand for biofuels accompanied by the enabling policies has triggered the industries to undertake biofuel production and has resulted in Jatropha and Pongamia in becoming headlines of bioenergy development in recent years. However, barriers include insufficient knowledge on suitability of Jatropha and Pongamia for various regions, lack of organized breeding program in the crops and limited agronomic and input response studies put forward in the initiative for generating information and feasibility of the crops. Many a times without much supporting evidence, tall claims about these plants in terms of their yield potential, water and nutrient requirements and tolerance to many pests and diseases are made. In this paper we report the findings of our strategic and development research done over last five years along with the challenges and opportunities to harness the potential of biodiesel plantations for protecting the environment while improving the rural livelihoods without compromising food security.

Research Approach

Government of India has initiated a targeted strategic research through the institutions network in the country under the leadership of National Oilseeds and Vegetable Oils Development Board (NOVOD). In Andhra Pradesh, state government initiated a research program in 2005 on Jatropha *curcas* by adopting the consortium approach of different institutions such as International Crops Research Institute for the Semi Arid Tropics (ICRISAT), Central Research Institute for Dryland Agriculture (CRIDA), Acharya N G Ranga Agricultural University (ANGRAU), National Bureau of Plant Genetic Resources (NBPGR), Indian Institute of Chemical Technology (IICT), and Directorate of Oil Seeds Research (DOR). The DOR withdrew from the consortium after two years. Different institutes are undertaking development and strategic research in the area of their expertise and jointly making steady strides in the area of biofuel research. In addition, there are public-private partnership (PPP) project supported by Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) and research projects supported by International Fund for Agricultural Development (IFAD), Rome and corporates.

Variability in the Existing Germplasm of *Jatropha* and *Pongamia* in India

Understanding the existing variability for different characters amongst the seed samples of Jatropha and Pongamia is very important to harness the potential through crop improvement. The NBPGR along with the consortium partners of the GoAP project have collected number of seed samples of Jatropha. Out of these samples based on the oil content and geographical spread of collection as well as the samples received from other researchers, 124 samples were analyzed for their oil content, seed size (100 seeds weight), and germination percentage.

Further, these samples were grown in fields at ICRISAT to assess the variability for other agronomic characters as well as to confirm the genetic variability for oil content and seed weight when grown under uniform environment. Wide range of variability for different plant characteristics amongst 124 lines of Jatropha was recorded.

Large variability amongst the samples of Jatropha seeds for oil content (27.8 to 38.4%) and hundred seeds weight (44 to 72.6) was recorded earlier (Wani *et al.*, 2007). The plant height varied from 64.3 to 196.6 cm with a mean of 123 cm, number of branches varied from 1 to 37.7 with a mean value of 7.7, along with a stem girth varying from 6.3 to 44.7 cm with a mean value of 20.5 cm amongst the samples grown in field for three years. Other plant growth characters such as North-South spread (6 to 212 cm with average of 103 cm) and East-West spread (5.7 to 211 cm with average of 101.4 cm) varied significantly amongst the plants grown from different seed samples. Along with the vegetative growth parameters different plants varied for the flowering characteristics such as number of flowering branches varied from 1 to 7.2 per plant with mean of 3 and number of inflorences per plant varied from 1 to 8.8 with a mean of 3.1 per plant amongst different seed samples. Most importantly large variation for female to male flower ratios (3.5 to 16.5) was also observed amongst different samples with a mean of 1:10 during the first flowering season after planting. Many plants yielded fruits and variation for the yield determining characters such as number of female flowers (2 to 45), pod bunches per plant (1 to 7), number of pods per plant (3 to 90), and seed yield (28 to 270 g) was observed. Seed oil content varied from 27.4 to 40.6 per cent amongst different accessions with a mean oil content of 34.3 per cent (Table 1). During the fourth year seed yield of different plants from Jatropha *curcas* accessions varied a lot with a maximum seed yield of 1.4 to 1.6 kg per plant in a block evaluation trial with spacing of 3x2 m reaching to 2.7 t ha^{-1}.

Similar evaluation of Pongamia accessions was also done and variation for plant growth parameters is recorded. The plant height varied from 135 to 380 cm with a mean of 243 cm, number of branches varied from 3 to 25 with a mean of 13, stem girth varied from 10 to 40 cm with a mean of 54 cm, North-South spread varied from 40 to 300 cm with a mean of 134 cm, East-West spread of the trees varied from 45 to 260 cm with average of 127 cm (Table 2). During the fourth year although sparse flowering was recorded no significant fruit yield was recorded from the plants grown from the seeds.

Table 1. Variation for oil content and plant growth parameters in Jatropha *Curcas* accessions, ICRISAT, Patancheru, 2008

Acc. Name	Accessions number	Plant ht (cm)	Branches/ plant	Stem girth (cm) at 10 cm ht.	N-S spread (cm)	E-W spread (cm)	Crown area (m2)	No. of flowering branches	No. of inflorescence per plant	Female: Male flowers ratio	No.of female flowers	Pod bunches per plant	Pods #/ plant	Pods Nos harvested	Pod yield per plant (g)	Seeds #/ plant	Seed yield per plant (g)	Total seed yield per plant (g)	Total oil content
BAAS-42	ICJC06016	122.60	6.20	24.00	103.00	114.60	0.78	3.60	3.60	5.41	7.60	2.25	8.00	-	-	-	-	-	38.10
SNES-26	ICJC06084	113.00	3.40	18.40	90.60	90.00	0.64	2.00	2.00	-	-	-	-	-	-	-	-	-	38.10
IJC-2	ICJC06111	87.67	5.67	12.00	60.00	58.33	0.28	-	-	-	-	-	-	-	-	-	-	-	38.40
BAAS-45	ICJC06018	127.00	7.20	23.40	142.00	150.60	1.57	4.60	4.60	9.32	6.00	2.60	35.00	-	-	-	-	-	38.60
SNES-37	ICJC06088	153.00	16.20	32.60	170.00	169.00	2.64	2.80	2.80	16.55	9.00	7.00	74.00	72.00	257.20	133.00	114.50	-	38.90
SNES-18	ICJC06077	95.20	4.00	14.60	79.00	71.80	0.55	3.50	3.50	-	-	2.00	-	-	-	-	-	-	39.00
SNES-40	ICJC06091	163.00	16.80	30.20	172.80	189.00	2.72	2.80	2.80	14.73	8.80	6.00	50.00	52.00	160.60	123.00	86.20	-	39.10
SNES-23	ICJC06081	103.40	3.80	16.20	82.60	86.00	0.75	2.00	2.00	-	-	-	12.00	-	-	-	-	-	39.20
SNES-25	ICJC06083	89.00	3.20	14.00	81.00	73.80	0.47	-	-	-	-	-	-	-	-	-	-	-	39.40
BAAS-51	ICJC06019	114.00	5.20	21.60	118.00	110.60	1.06	3.20	3.20	9.20	7.20	1.33	18.00	-	-	-	-	-	40.60
IJC-13	ICJC06122	71.67	1.67	6.33	6.00	5.67	0.00	-	-	-	-	-	-	-	-	-	-	-	34.40
BAAS-30	ICJC06040	130.40	6.80	19.00	112.00	97.60	1.00	2.00	2.00	13.93	2.80	1.25	30.00	-	-	-	-	-	34.50
BAAS-48	ICJC06046	128.00	7.00	21.20	96.80	104.80	0.78	2.50	2.50	14.25	2.00	2.50	21.00	-	-	-	-	-	34.50
BAAS-37	ICJC06044	125.00	6.00	19.60	108.60	97.00	0.97	2.25	2.25	9.30	4.25	1.67	14.00	-	-	-	-	-	34.60
SNES-16	ICJC06075	115.00	3.80	17.80	94.00	83.00	0.63	2.50	2.50	-	-	1.00	6.00	-	-	-	-	-	34.60
BAAS-67	ICJC06048	102.60	3.00	18.40	66.40	81.20	0.44	2.00	2.00	12.00	3.00	-	15.00	-	-	-	-	-	34.70
IJC-14	ICJC06123	113.00	4.67	17.00	78.67	82.00	0.56	-	-	-	-	-	-	-	-	-	-	-	27.80
IJC-1	ICJC06110	65.00	3.67	13.67	16.67	17.00	0.02	-	-	-	-	-	-	-	-	-	-	-	28.00
CSMCRI-9	ICJC06105	196.60	13.20	31.60	85.70	86.90	0.39	-	-	-	-	-	-	-	-	-	-	-	28.54
IJC-4	ICJC06113	85.67	4.67	17.33	32.00	31.33	0.09	-	-	-	-	-	8.00	33.00	30.00	76.80	71.00	44.00	28.60
	Mean	123.04	7.69	20.49	103.12	101.43	1.01	2.96	3.11	9.85	7.22	2.70	23.97	40.52	103.32	91.34	75.64	79.98	34.33
	Standard deviation	30.94	6.10	6.38	42.55	43.68	0.88	1.12	1.41	3.56	6.45	1.37	19.66	22.34	79.86	39.46	35.39	78.58	2.69
	Minimum	64.33	1.00	6.33	6.00	5.67	0.00	1.00	1.00	3.51	1.80	1.00	3.00	4.00	12.80	9.00	8.60	28.13	27.40
	Maximum	196.60	37.67	44.67	212.00	211.00	4.15	7.25	8.80	16.55	45.00	7.00	90.00	72.00	257.20	159.00	131.00	269.30	40.60

Table 2. Variability in *Pongamia* accessions grown at ICRISAT, 2008

Accessions	Plant #	Plant ht (cm)	Branches/ plant	Stem girth (cm) at 10 cm ht.	N-S spread (cm)	E-W spread (cm)
IPC-1	1	175	10	18	64	47
	2	300	12	16	85	86
	3	250	12	18	85	85
IPC-2	1	300	12	18	100	80
	2	285	13	16	105	110
	3	200	6	12	135	150
IPC-3	1	225	12	20	148	155
	2	225	15	22	135	145
	3	136	5	22	161	90
IPC-4	1	250	20	20	165	115
	2	250	18	18	110	170
	3	135	8	10	54	45
IPC-5	1	240	10	15	100	100
	2	200	3	20	120	125
	3	175	3	15	40	45
IPC-6	1	200	6	18	120	55
	2	220	4	20	110	100
	3	200	15	14	150	140
IPC-7	1	205	10	15	60	75
	2	300	12	18	100	150
	3	300	10	17	150	200
IPC-8	1	250	16	20	180	125
	2	310	12	24	200	160
	3	235	15	23	160	140
IPC-9	1	310	20	30	200	210
	2	260	25	28	160	176
	3	380	24	40	300	260
IPC-10	1	230	24	25	180	165
	2	300	25	28	200	200
	3	20	20	20	150	130
	Mean	242.87	13.23	20.00	134.23	127.80
	Standard	55.36	6.52	5.95	54.18	52.91
	Minimum	135.00	3.00	10l00	40.00	45.00
	Maximum	380.00	25.00	40.00	300.00	260.00

Assessment of Variability in Jatropha and Pongamia Accessions Using Molecular Markers

Amplified fragment length polymorphism (AFLP) was employed to assess the diversity in the elite germplasm collection of Jatropha *curcas*, which has gained tremendous significance as a biofuel plant in India and many other countries recently. Forty-eight accessions from six different states of India were used 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 seven primer combinations used, a variety of marker attributes like polymorphism information content (PIC), marker index (MI) and resolving power (RP) values were calculated. 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 combination and the MI values were observed in the range of 7.05 (E-ACA / M-CAA) to 9.92 (E-AGC / M-CTA) with an average of 8.70 per primer combination, the RP was recognized the real attribute for AFLP to determine the discriminatory power of the primer combination. The RP values for different primer combinations varied from 3.87 (E-ACA / M-CAT) to 7.85 (E-AGG / M-CTA) with an average of 6.14.

Genotyping data obtained for all 680 polymorphic fragments were used to group the accessions analysed using the UPGMA- phenogram and principal component analysis (PCA). Majority of clusters/grouped obtained in phenogram and PCA contained accessions as per geographical locations. In general, accessions coming from Andhra Pradesh were found diverse as these were scattered in different groups, showed occurrence of higher number of unique/rare fragments and had greater variation in percentage oil content. Molecular diversity estimated in the present study combined with the datasets on other morphological/agronomic traits will be very useful for selecting the appropriate accessions for plant improvement through conventional as well as molecular breeding approaches (Leela *et al.*, 2009).

Water Requirement of Jatropha Plantation in the Semi Arid South India Location

Soil moisture is monitored in the Jatropha plantation (seedlings planted in November 2004) at ICRISAT from November 2005 using the neutron probe (Troxler model 4302) at 12 representative locations in the plot. Weather was monitored at the ICRISAT agrometeorological observatory, Patancheru. Daily reference crop evapotranspiration (ET_0) was computed following the FAO Penman-Monteith method (1998). Evapotranspiration requirements of Jatropha under ideal soil moisture conditions were estimated based on ET_0 and crop coefficients estimated for different phenophases. Evapotranspiration (ETadj) values under actual field conditions of Jatropha plantation were estimated from soil moisture measurements using the standard water balance equation.

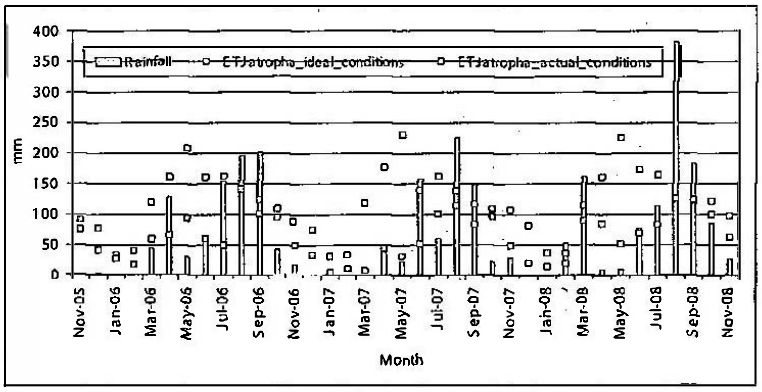

Figure 1. Variation of rainfall and ET in the Jatropha plantation

Monthly crop evapotranspiration values indicate (Figure 1) that during April to June, ET 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 ET requirements; this period coincides with flowering and fruit set stage. Jatropha has used about 75 to 90% of the rainfall received in the past three years; lower percentage utilization occurred when the rainfall distribution was erratic, though the rainfall amount was high. In the year 2008, rainfall till 30th November was 1103 mm, however, total rainfall during June and July was only 190 mm compared to the normal of 305 mm. August rainfall was 382 mm compared to the normal of 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 ET 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. Study indicates that contrary to the belief that Jatropha needs less water, under favorable soil moisture conditions, Jatropha could use large amounts of water for luxurious growth and high yield.

Effect of Pruning/ Canopy Management on the Growth Characteristics of Jatropha *Curcus*

The flowering occurs at the terminal portion of the branches in Jatropha and along the branches in case of Pongamia. Therefore, pruning is recommended to increase the number of fruiting branches in Jatropha, by nipping the terminal bud to induce secondary branches. Likewise the secondary and tertiary branches are to be pinched or pruned at the end of first year. In our study half the plants in block plantation were pruned at 45 and 75 cm during first year and second year of growth during summer (February –March) when all leaves were dropped and half were grown without pruning. During the third year, top one-third of secondary and tertiary branches were nipped off in plants under pruning treatment. The effect of pruning was observed on plant height, stem girth at 10 cm above ground, number of branches, crown area, and volume index during third year. The results showed that pruning significantly influenced plant growth characteristics (Figure 2). The pruning of Jatropha plants significantly ($p < 0.05$) increased plant height (224 cm). Stem girth (36 cm), and volume index (29.4) compared to non-pruned treatment plants. However, there was no significant increase in number of branchlets and crown area due to pruning of plants. There was no significant difference for pod yield, seed yield and shelling percentage (67 vs 70%) across three fertility management treatments between the pruned and non-pruned plants. However, the bushy nature of the pruned plants facilitates seed harvesting as well as recycling of plant nutrients. We will be studying the effect of pruning on seed yield and yield parameters during the fourth year. Once in ten years, the plant may be cut back leaving one-foot height from ground level for rejuvenation in case of Jatropha. The growth is quick and the plant starts yielding in about a year period. This will be useful to induce new growth and to stabilize yield. In a study of canopy management in North East Thailand, cutting of Jatropha at height of 50 cm from bottom was found reasonable to maintain a compact bush form. The end of dry season was found optimum for cutting back as the plants go in dormancy after the fruiting season.

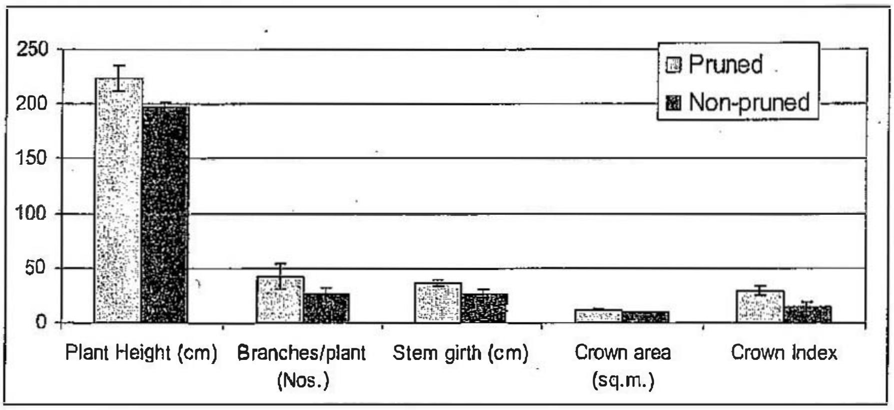

Figure 2. Growth characteristics of Jatropha plants due to summer pruning during the 3rd of establishment

Thinning twice after one and two months of cut back was recommended to promote useful fruiting branches and to maintain a compact bush form (Sakaguchi and Somabhi, 1987).

Nutrient Content of Fallen Leaves, Pruned Branches, Seeds and Seed cake of Jatropha

As the Jatropha has to be grown on degraded lands as per the policy of the GoI, it is critical to assess the nutrient demand of the plants and assess return of plant nutrients as well as carbon to the soil that can contribute in improving soil health. Jatropha plants have a unique mechanism of drought tolerance by dropping all its leaves during the moisture stress and minimizing its water requirement. This characteristic of Jatropha comes handy for rehabilitating the degraded lands which are severely depleted in organic carbon and as a result have low water holding capacity.

Using the different plant parts samples from the various treatments at ICRISAT research experiments we attempted to draw general principles, which can help in improving the management of Jatropha plantations. The nutrient content analysis of different plant parts results, presented in the Table 3, revealed that highest nitrogen content of 49,500 mg kg^{-1} was recorded in seed cake followed by 22,800 mg N in seeds, 16,100 mg N in pruned shoots, and 9,500 mg N per kg fallen leaves. Phosphorus content in plant parts varied from 700 mg P in leaves to 4,800 mg per kg in seeds (Table 3). Seed were rich in nitrogen content with 22,800 mg N per kg followed by potassium (8,100 mg kg^{-1}), phosphorus (4,800 mg kg^{-1}), sulphur (1,400 mg kg^{-1}), zinc (17.8 mg kg^{-1}), and boron (15 mg kg^{-1}). Fallen leaves were rich in potassium (10,000 mg kg^{-1}), followed by nitrogen (9,500 mg kg^{-1}), sulphur (941 mg kg^{-1}). Nitrogen and Sulphur contents amongst the plant parts were highest in seeds, followed by stem and least in leaves. Potassium content was highest in pruned shoots, followed by leaves and least in seeds. Amongst the plant parts boron content was highest in leaves followed by seeds, and least in pruned shoots (Table 3).

The moss of fallen leaves and nutrient content in case of Jatropha plantations varied with the age (Table 4) as well as with the fertility treatment. Leaf fall in case of three years old plants was 2.6 folds more than incase of one-year plants (1451 vs. 552 g $plant^{-1}$) however, nitrogen concentration in fallen leaves was 32 per cent higher (11400vs.8600 mg kg^{-1}) in case of leaves from one-year plants that of the leaves from three-year plants.

Table 3. Nutrient content (mg kg^{-1}) in fallen leaves, shools, seeds and seed cake of *Jatropha Curcus*, ICRISAT. Patancheru

	N	P	K	S	B	Zn
Shools	16100	2400	23300	1289	11.2	43.6
Leaves	9500	700	10000	941	33.8	23.3
Seeds	22200	4800	8100	1400	15.0	17.8
Seed Cake	49500	4400	8900	2114	18.1	32.2

Table 4. Quantity and nutrient content and amounts of nutrients returned through fallen leaves in Jatropha plantation soil of different ages, ICRISAT, Patancheru

Fallen dry leaf litter during 2007								
Age of the plant	Fertilizer dose	Dry leaf (g/plant)	%N	%P	%K	Nutrient recycling by leaf litter		
						N (kg/ha)	P (kg/ha)	K (kg/ha)
1 year old	120g Urea, 170g SSP and 50g Gypsum	552.5	1.14	0.06	1.10	15.7	0.8	15.2
3 years old	100g Urea and 38g SSP	1451.1	0.86	0.08	0.95	20.8	2.0	23.0

Nutrient Recycling and Organic Carbon Addition through Fallen Leaves

In case of Jatropha plants fertilized with 90 kg N ha^{-1} nutrient recycled were calculated using leaf mass data and different nutrient concentrations in the fallen leaves. Three major plant nutrients *viz*, nitrogen, phosphorus and potassium recycled were quantified. One-year plantation with 3x2 m spacing with 1666 plants per ha returned 15.7 kg N, 0.8 kg P, and 15.2 kg K per ha. Three-year old plantation recycled 20.8 kg N, 2 kg P, and 23 kg K per ha through fallen leaves. Recycling of nutrients through fallen leaves has very important role in sustaining the productivity of Jatropha plantations as nutrients from deeper soil depth used by the plants will be recycled through decomposition in top soil layer. Secondly, in addition to the nutrients recycled within the soil-plant system, soils will be enriched with valuable organic carbon fixed by the plants and added to the soil through fallen leaves. Considering that 2.5 t fallen leaves ha^{-1} containing 40% organic carbon additions to the soil works out to be around 1000 kg per ha in case of three-years old plantation. Addition of 1000 kg organic carbon fixed from the atmosphere not only reduces the concentration of CO_2 in the atmosphere but will increase system's productivity through improved soil organic carbon addition which is critically needed in the tropics. Tropical soils are poor in their organic carbon content (Wani *et al.*, 2003; Sahrawat *et al.*, 2008) and through improved cropping systems and improved management options good potential for carbon sequestration exists in the semi arid tropical systems. Pigeon pea-based systems in the SAT fixed 350 kg C per ha in Vertisols, upto 150 cm depth, largely through fallen leaves and root mass left in the soil. Carbon sequestration could help improving rural livelihoods in the SAT through harnessing the potential of tropical agricultural systems by adoption of improved soil, water, nutrient, and crop management options (Wani *et al.*, 2007).

Under tropical conditions, return of 1000 kg C per ha per year is quite substantial through Jatropha plantations and this additional environmental benefit in addition to renewable energy needs to be considered. There is an urgent need to assess the potential of biodiesel plantations in the tropical countries for total carbon sequestration including in the soil, as well as through C replacement of fossil fuel-bosed diesel. Carbon sequestration is one of the most important environmental services provided through forests and agricultural systems in the tropics. At ICRISAT our team is already addressing systematically this issue of C sequestration in case of Jatropha and Pongamia plantations under different systems. Our studies on Pongamia showed that this plant has a very good potential for C sequestration along with its inherent ability to fix atmospheric nitrogen through biological nitrogen fixation.

Nutrients Requirement for Targeted Jatropha Seed Yield Based on Nutrient Budgeting

Detailed nutrient concentrations in different plant parts along with amount of plant materials returned to soil and seeds removed from the fields for the purpose of oil extraction enables us to look at the nutrient requirements to achieve the targeted crop yields. Our results showed that one ton seeds of Jatropha remove 22 kg N, 5 kg P and 8 kg K per ha (Table 5). Average productivity of 3 t seeds ha^{-1} will remove 66 kg N, 15 kg P and 24 kg K per year per ha. In order to sustain the productivity of the field at this level we need to return equivalent quantities of N, P, and K in a simple arithmetic terms (Table 6). However, nutrient availability in soil from different sources of nutrients varied significantly depending on the C:N ratio, biological activity along with soil moisture and temperature. For mineral fertilizers recovery of nutrients, for example in case of N, is about 40-45%, where as from organic matter of wider C:N ratio, such as fallen leaves with 40:1 C:N ratio, N and other nutrient availability will be far less

Table 5. Nutrient uptake through seeds (kg/ha) at different levels of seed production .

Nutrient	Seed yield (t ha^{-1})				
	1	2	3	4	5
N	22.2	44.4	66.6	88.8	111
P	4.8	9.6	14.4	19.2	24
K	8.1	16.2	24.3	32.4	40.5
S	1.4	2.8	4.2	5.6	7
B	0.015	0.03	0.045	0.06	0.075
Zn	1.7	3.4	5.1	6.8	8.5

Table 6. Effect of different fertilizer treatments on growth and yield parameters of Jatropha *Curcus*, ICRISAT, Patancheru, 2008

Treatment*	Fertilizer dose	Plant Pod wt (kg)	Plant Seed wt (kg)	Shelling %	100 seed weight (g)
T-1	125 g urea + 65 g DAP	2.04	1.44	70.3	75.1
T-2	125 g urea + 81 g DAP	1.31	0.92	69.9	75.3
T-3	155 g urea + 65 g DAP	3.54	2.44	68.9	74.1
T-4	155 g urea + 81 g DAP	3.59	2.49	69.4	74.0
T-5	Control	2.20	1.49	68.1	65.4

** T1 = 65 g ; T2 = 81 g ; T3 = 81 g ; T4 = 81 g ; T5 = control*

(<20 per cent)during first year of application. Leaf fall data and return of nutrients through leaf fall indicated that three-years plantation returned 21 kg N, 2 kg P, and 23 kg K per ha. Applying the efficiency of release and uptake of N from the fallen leaf material it may able to provide about 5 kg N per ha, at best. It means for achieving target yield of 3 t ha^{-1} seeds, one will need to meet the demand of additional 60 kg plant available N per ha and applying the basis of even 50% recovery from the chemical fertilizers one will need to apply about 120 kg N per ha. Similar will be the case for phosphorus which will need application of 14 kg P i.e., 38 kg P_2O_5 per ha. These studies clearly indicate that for sustainable Jatropha production at any level will definitely need application of plant nutrients in sufficient quantities. Through leaf fall and application of oil seed cake a byproduct after extraction of oil can meet the partial plant demand for the nutrients, however, nutrients such as N and P will have to be supplied externally. Other nutrients such as K, Zn, B, and S may not be needed to apply regularly as removal of these nutrients through seeds is quite less and return through leaf fall is considerable. However, detailed studies on nutrient release patterns from the fallen leaf material as well as oil seed cake are needed to arrive at the right nutrient dose applications to sustain seed yields.

Effect of Fertilizer Treatments on Plant Growth

Pongamia, a multipurpose leguminous tree containing non-edible oil, grows widely in India. Oil extracted from the seeds of Pongamia is used as energy source as well as in tanneries, while the cake (a by-product after extracting oil) was found to be rich in all plant nutrients in general and nitrogen (4.28%) and sulphur (0.19%) in particular. Both nitrogen and sulphur were found to be deficient in 100% and 80% soil samples from farmers' fields in Powerguda village of Adilabad district, respectively. Use of Pongmia seed cake as a source of plant nutrients for maize, soybean and cotton was found beneficial in participatory research and development (PR&D) trials on farmers' fields. Further, application of critically deficient micronutrients such as zinc and boron and secondary nutrient sulphur increased crop yields by 16.7% and 19% in soybean and cotton, respectively. Additional B:C ratios of 5.03, 1.81 and 2.04 were obtained for soybean, maize and cotton, respectively with use of cake as a source of N, however, it needed higher initial investment (Table 7).

Intercropping with Jatropha and Pongamia

When Jatropha and Pongamia are grown on low quality arable lands, it is possible to grow intercrops which can provide additional income to the farmers. However, as indicated in the nutrient budgetary approach, appropriate amendments with necessary requirements are a must to ensure good crop productivity. At ICRISAT research center, where agronomic and different accessions evaluation trials of Jatropha and Pongamia are conducted we have evaluated the feasibility of growing different crops as intercrops with Jatropha and Pongamia. In these experiments we have observed that crops like sorghum, pearl millet, pigeon-pea, soybean, mung bean, chickpea, sunflower, and safflower can be successfully cultivated during rainy season and post-rainy season. Productivity of these crops in terms of grain yield varied from 0.29 t ha^{-1} in case of green gram to 1.5 t ha^{-1} in case of sorghum. Total economic value from additional income through grains and fodder from these crops varied from Rs.5355/- to Rs.20430/- per ha in case of Jatropha intercrops (Table 8). With Pongamia plantations

Table 7. Plant height, cotton yield, total income, additional cost over farmers' practice and N-fertilizer equivalent in farmers' fields, Powerguda, rainy season, 2005

Treatment	N applied (kg ha^{-1})	N fertilizer equivalent using FP as control	Cotton yield (kg ha^{-1})	Total Income (Rs ha^{-1})	Additional cost over practice (Rs ha^{-1})	Additional income farmer's	Additional BCR Rs. ha^{-1}
Farmer's practice (FP)	80	–	890	16990	–	–	–
Pongamia Seed Cake (PC) 3000 kg ha^{-1}	128	160	1790 (101)	34070	8390	17080	2.04
PC 1500 kg ha^{-1} + 100 kg DAP + 100 kg Urea ha^{-1}	128	104	1160 (29.5)	22000	5275	5010	0.95
Mineral fertilizer 200 kg DPP + 200 kg Urea ha^{-1}	128	95	1065 (19)	20235	2160	3245	1.50
SE	–	–	124.8	–	–	–	–

peralmillet and pigeon-pea have been successfully grown achieving productivity of 0.5 t ha^{-1} in case of pigeon-pea and 1.1 t ha^{-1} in case of peralmillet grains. Total economic value from the additional income of intercrops in case of Pongamia intercrops systems is around Rs.10700/- per ha (Table 8).

The intercrops data and the incomes are from four years old plantations of Jatropha (pruned) and Pongamia grown on shallow black soils with low fertility and higher PH.

Rhizosphere Microbiology of Jatropha and Pongamia *Plants*

Sustainability of plant soil systems is largely governed by the flora and fauna biodiversity in the rhizosphere soils of the plant. Microbial biomass is undifferentiated parameter of different microorganisms in soil, which play an important role in controlling nutrient cycling and availability to plants.

The study to evaluate the effect of Jatropha and Pongamia plants on the soil biological activity at different locations and characterizing the difference between rhizosphere and non-rhizosphere soils of the plants was undertaken. Soil samples (rhizosphere and non-rhizosphere) from four different locations (ICRISAT campus, Velchal, Siddhapur, Kothalapur) in Andhra pradesh, India were studied for microbial counts, microbial biomass, and dehydrogenase enzyme activity in the soil samples.

The rhizosphere soil in locations planted with Jatropha and Pongamia recorded high populations of bacteria, fungi, actinomycetes as well as dehydrogenase activity (Figure 3a,

Table 8. Grain and fodder yield of different crops grown as intercrops with four years old Jatropha and Pongamia plantation, rainy season, 2008

Biodiesel crop	Intercrop	Grain (t/ha)	Grain Value (Rs)	Stalk (t/ha)	Foddor Value (Rs)	Total Economic Value (Rs)
Jatropha						
	Sorghum	1.50	9300	3.71	11130	20430
	Pearl Millet	1.18	7080	2.07	4140	11220
	Pigeonpea	0.59	9381	2.07	2070	11451
	Soybean	0.51	5355	0.67	0	5355
	Mungbean	0.29	5046	1.36	0	5046
	Chickpea	1.01	16016	0.89	445	16461
	Sunflower	0.98	14798	2.85	0	14798
	Safflower	0.54	8910	2.33	0	8910
Pongamia						
	Pearl Millet	1.14	6840	1.93	3860	10700
	Pigeonpea	0.57	9063	1.62	1620	10683

3b, 4a, 4b). The values of soil respiration, microbial biomass N, C and mineral N were high when compared with non-rhizosphere soil samples (Figure 3a, 3b, 4a, 4b).

High microbial population in rhizosphere soil indicates increase soil biological activity, which was also observed with increased microbial biomass C and N. Number of bacteria and actinomycetes in the rhizosphere soils of Jatropha were more by 40 and 50% respectively than from the non-rhizosphere soil samples. Numbers of fungi in the rhizosphere soil samples were more by two folds than the non-rhizosphere soil samples. Similar results were observed for higher number of bacteria, fungi and actinomycetes in rhizosphere soil samples of Pongamia than the non-rhizosphere soil samples also from two locations (Figure 4a, 4b).

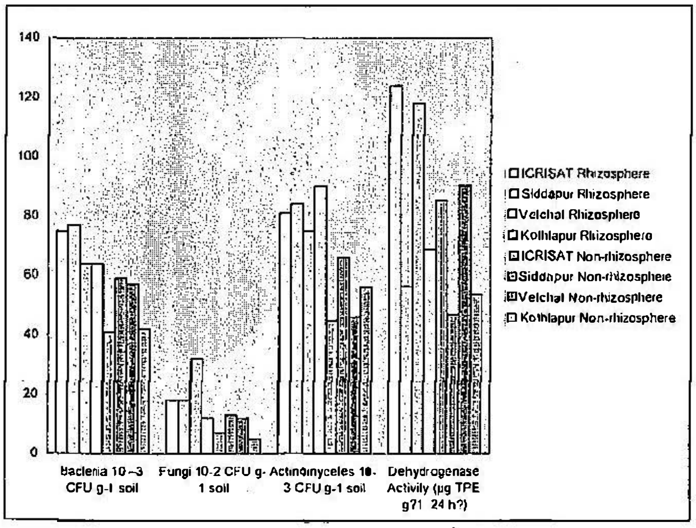

Figure 3a. Mean of Microbial parameters, Enzyme activities of rhizosphere and non-rhizosphere soils planted with Jatropha at different locations in Andhra Pradesh, India

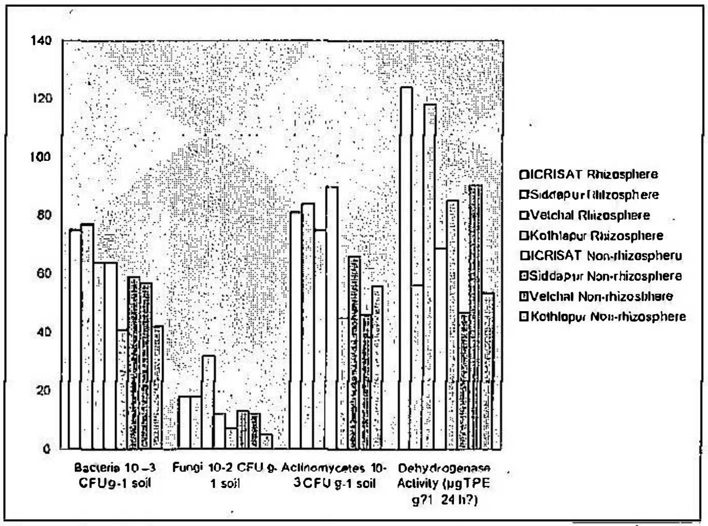

Figure 3b. Mean of Biological activities of rhizosphere and non-rhizosphere soils planted with Jatropha at different locations in Andhra Pradesh, India

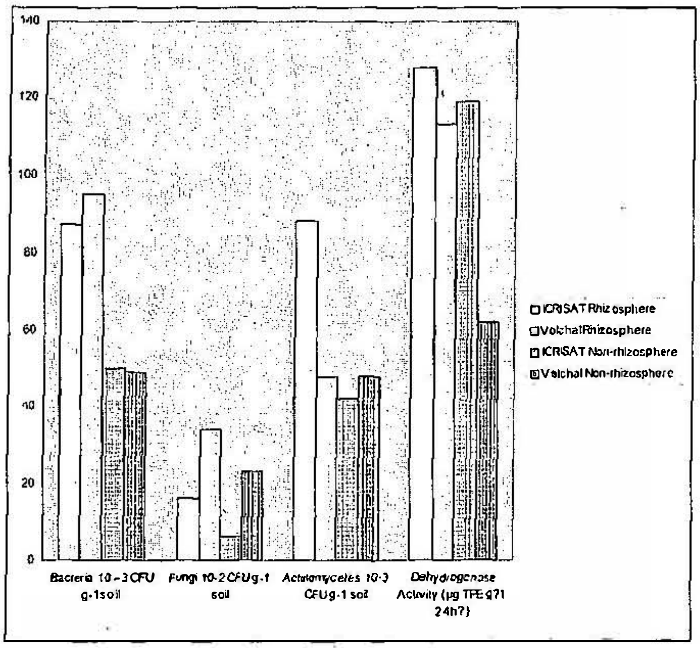

Figure 4a: Mean of Microbial parameters, Enzyme activities of rhizosphere and non-rhizosphere soils planted with Pongamia at different locations in Andhra Pradesh, India

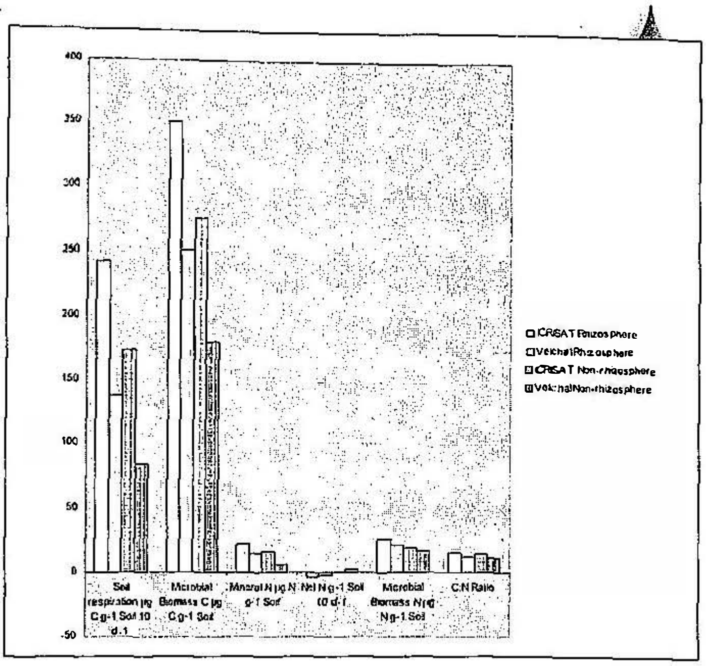

Figure 4b: Mean of Biological activities of rhizosphere and non-rhizosphere soils planted with Pongamia at different locations in Andhra Pradesh, India

The highest dehydrogenase activity was found in rhizosphere soils planted with Jatropha and Pongamia. The high values of microbial C and N in the rhizosphere soil indicated stimulation of biological activity in soil due to rhizosphere effects. Jatropha and Pongamia plants grow at different field conditions. This study shows that plantation of Jatropha and Pongamia stimulated soil microbial populations, which in turn recorded high soil biological activity as well as enzymatic activity due to rhizosphere activity. Although Jatropha and Pongamia plants are non-edible for human beings and animals, microbes were not adversely affected but were stimulated due to rhizosphere effect of Jatropha and Pongamia.

Conclusion

There is an urgent need for undertaking systematic and in-depth research on various aspects of Jatropha and Pongamia cultivation, which are receiving attention of the policy-makers, as well as development investors worldwide. The research at ICRISAT in partnership with different institutions revealed that in case of Jatropha and Pongamia, good variability exists amongst different accessions collected from different regions. In order to harness the full potential of Jatropha and Pongamia appropriate management practices and agronomic practices along with breeding of high yielding and high oil containing cultivars is must. The agronomic trials have revealed that for achieving targeted yields using nutrient budgetary approach 3 t ha^{-1} seeds 120 kg N and 38 kg P_2O_5 per ha are required. The nutrient requirements of Jatropha can be met partly through the nutrients provided by fallen leaves as well as application of oil seed cake. Molecular techniques also revealed variability in the germplasms which can be harnessed for developing improved cultivars. Water requirement of three years old Jatropha plantations indicated that evapo-transpiration demand under no moisture stress for Jatropha varied from 1150–1350 mm per year. Additional income through growing intercrops in pruned Jatropha and Pongamia plantations is feasible when they are grown on low quality arable lands. Concerted efforts are required to harness the potential through science-led development of Jatropha and Pongamia initiatives.

REFERENCES

- D'Silva E., Wani S.P. and 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, Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 28 pp.
- Francis G. Edinger R. and Becker K. 2005. A concept for simultaneous wasteland reclamation, fuel production, and socio-economic development in degraded areas in India: need, potential and perspectives of jatropha plantations. Natural Resources Forum, 2005, 29, 12-24.
- ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 2006. ICRISAT Archival Report 2006. The seedlings of success in the semi-arid tropics nurtured. Patancheru, Andhra Pradesh, India: ICRISAT. 417 pp.
- ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 2007. Biopower Strategy.
- IEA (International Energy Agency). 2007. World Energy Outlook 2007, China and India
- Insights, Paris. 2007.
- IPCC. 2007. Climate Change 2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (eds) Cambridge University Press, Cambridge, UK, 996 pp.
- Leela T., Suhas P. Wani, Seetha Kannan, Naresh B., David A., Hoisington, Prathibha Devi, Rajeev K., Varshney and Sreedevi T.K. 2009. AFLP-based molecular characterization of an elite germplasm collection of Jatropha curcas L., a biofuel plant. Journal of Plant Science (in press).
- Sahrawat K.L., Rego T.J., Wani S.P. and Pardhasaradhi G. 2008. Stretching soil sampling to watershed: Evaluation of soil test parameters in a semi-arid tropical watershed. Soil Science and Plant Analysis. pp. 39.
- Sakaguchi S and Somabhi M. 1987. Exploitation of promising crops in northeast Thailand. Agricultural Development Research Center, Northeast Thailand, pp.61.
- Wani S.P., Pathak P., Jangawad L.S., Eswaran H. and Singh P. 2003. Improved management of Vertisols in the semi-arid tropics for increased productivity and soil carbon sequestration. Soil Use and Management (2003) 19, 217-222.
- Wani S.P., Mohammed Osman, D'Silva E and Sreedevi *et al.* 2006a. Improved livelihoods and environmental protection through biodiesel plantations in Asia. Research and information system for Developing countries. Vol.8:2, pp.11-29.
- Wani S.P., Sreedevi T.K. and Reddy B.V.S. and team. 2006b. Biofuels : Status, Issues and Approaches for harnessing the potential. Presentation made at CII Godrej Center, Hyderabad during 29-30 June 2006.
- Wani S.P., Sahrawat K.L., Sreedevi T.K., Bhattacharyya T. and Sreenivasa Rao CH. 2007. Carbon sequestration in the semi-arid tropics for improving livelihoods. International Journal of Environmental Studies, Vol. 64, No. 6, December 2007. 719-727.
- Wani S.P. and Sreedevi T.K. 2007. Strategy for Rehabilitation of Degraded Lands and Improved Livelihoods through Biodiesel Plantations. In proceedings of 4th International Biofuels Conference held during 1-2 February 2007 at New Delhi. pp. 50-64