Ecological Economics xxx (2010) xxx–xxx

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Jatropha plantations for biodiesel in Tamil Nadu, India: Viability, livelihood trade-offs, and latent conflict

Pere Ariza-Montobbio [a,*], Sharachchandra Lele [b,1]

[a] Institute of Environmental Science and Technology, Universitat Autònoma de Barcelona (UAB), Barcelona, Spain
[b] Centre for Environment and Development, Ashoka Trust for Research in Ecology and the Environment (ATREE), Bangalore, India

ARTICLE INFO

Article history:
Received 17 January 2010
Received in revised form 20 May 2010
Accepted 21 May 2010
Available online xxxx

Keywords:
Biofuel
Biodiesel
Rural livelihoods
Jatropha curcas
Latent resource conflicts

ABSTRACT

Researchers, policy makers and civil society organizations have been discussing the potential of biofuels as partial substitutes for fossil fuels and thereby as a simultaneous solution for climate change and rural poverty. Research has highlighted the ambiguity of these claims across various dimensions and scales, focusing on ethanol-producing or oilseed crops in agricultural lands or Jatropha-type crops on common lands. We studied the agronomic and economic viability and livelihood impacts of *Jatropha curcas* plantations on private farms in Tamil Nadu, India. We found that Jatropha yields are much lower than expected and its cultivation is currently unviable, and even its potential viability is strongly determined by water access. On the whole, the crop impoverishes farmers, particularly the poorer and socially backward farmers. Jatropha cultivation therefore not only fails to alleviate poverty, but its aggressive and misguided promotion will generate conflict between the state and the farmers, between different socio-economic classes and even within households. The water demands of the crop can potentially exacerbate the conflicts and competition over water access in Tamil Nadu villages.

1. Introduction

The demand of energy for maintaining the societal metabolism of developed and emerging economies like India[2] has lead many governments to promote biofuels.[3] The Indian National Biofuel Policy aims at blending 20% bioethanol and biodiesel with gasoline and diesel respectively by 2017 (Government of India, 2009). Although biofuels are currently contributing less than 2% of transportation fuels globally, their production is growing rapidly, having tripled from 2000 to 2007 (Howarth et al., 2009). Understanding the socio-economic and environmental consequences of biofuel production is therefore critically important.

Integrated assessments of large-scale biofuel production (Giampietro et al., 1997, 2006; Russi, 2008; Giampietro and Mayumi, 2009) show that its low Energy Return on Investment (EROI) (Odum, 1971; Hall et al., 1986) compared to fossil fuels, imposes a heavy demand on land, water and labour per net GJ delivered. If biofuels are to replace fossil fuels in a major way in the current economy, the associated land use changes will be significant and will entail trade-offs across multiple dimensions (Russi, 2008). Biofuels will probably increase the Human Appropriation of Net Primary Production (HANPP) (Vitousek et al., 1986) to the detriment of the biomass available for other species (Haberl et al., 2004). The competition for water with other crops and economic activities will also increase due to their high water footprint (DeFraiture and Berndes, 2009; Gerbens-Leenes et al., 2009a,b). The claimed positive GHG emissions balance will be compromised by the "biofuel carbon debt" of converting forest or shrub ecosystems to energy crops (Fargione et al., 2008). The dramatic rise of prices for basic food staples in 2008 was arguably related in part to farmers switching from food crops to biofuels (Mitchell, 2008; Ewing and Msangi, 2009).

The above studies indicate negative consequences of biofuels globally. Nevertheless, some studies at a global scale, argue in favor of using marginal or "abandoned" crop lands to avoid competing with food crops (Fargione et al., 2008; Field et al., 2008; Tilman et al., 2009). Others argue in favor of small-scale production in the South, creating employment and income opportunities for local populations through contract farming, mainly using a new crop: *Jatropha curcas* (ICRISAT, 2007; UNESDA, 2007; Clancy, 2008). Jatropha is claimed to be a hardy drought-tolerant shrub that reclaims the land, prevents erosion, and responds better to organic manure than chemical fertilizers (Openshaw, 2000; Francis et al., 2005). These properties make this plant suitable to be cultivated both in marginal lands and in small farmers' plots. The Indian Government's biodiesel target is to be met through the cultivation of 13.4 million of hectares of "wastelands," precisely

* Corresponding author. Tel.: +34 935868102; fax: +34 93 5813331.
E-mail addresses: pere.ariza@uab.cat (P. Ariza-Montobbio), slele@atree.org (S. Lele).
[1] Tel.: +91 80 23635555; fax: +91 80 23530070.
[2] India's fast growing economy is increasing demand for petroleum, which has been growing at the average rate of 5% per year since 1991 (IEA, 2007). India meets 70% of its oil needs through imports, and 50% of the oil consumption is in the transport sector (Planning Comission, 2006).
[3] The EU has set a target of biofuels 10% substitution for transportation fossil fuels by 2020 and the USA has set a target of 36 billion gallons of ethanol a year by 2022.

0921-8009/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolecon.2010.05.011

Table 1
Distribution of sample farms surveyed by questionnaire and subset used in agronomic assessment, broken up by district and type of irrigation (with yielding farms given in brackets).

Type of irrigation	Sample size	Coimbatore	Thiruvannamalai
Irrigated	N in household survey	3 (3)	13 (6)
	N agronomic assessment	3	2
Rainfed	N in household survey	6 (3)	27 (3)
	N in agronomic assessment	6	3
Total	N in household survey	9 (6)	40 (9)
	N in agronomic assessment	9	5

with Jatropha (Government of India, 2003). But information on the region-specific field performance of Jatropha is limited. Some studies from Kenya have questioned the viability of Jatropha for smallholders (Tomomatsu and Swallow, 2007; Moraa et al., 2009) but they are based on estimated projections from experimental data. Others have focused on impacts of transferring public lands to Jatropha cultivation (GRAIN, 2008; Rajagopal, 2008). But governments are also promoting its cultivation on private lands, using both state-supported and corporate-supported contract farming approaches. These interventions in regions of poverty, agrarian distress and water scarcity have the potential to spark unanticipated conflicts and aggravate the already existing latent conflicts. The implications of Jatropha cultivation in the tropics need closer examination.

We carried out a study of different dimensions of Jatropha cultivation on private lands in Tamil Nadu state of southern India, one of the states leading in Jatropha cultivation, particularly on private lands. Carrying out a full-fledged integrated assessment was outside the scope of this study. We assessed impact at two different levels and focused on the dimensions of productivity, economic viability, distribution, and latent conflict. First, at the farm level, we asked whether Jatropha cultivation was indeed a productive and remunerative activity for the farmer from an agronomic (physical productivity) and economic sense. Second, at the household level, we asked what the livelihood trade-offs and changes in livelihood strategies were due to Jatropha cultivation, changes that would be relevant even if Jatropha was (or were to become) an economically remunerative activity. Third, at both levels, we sought to look for differences across socio-economic classes in adoption and in benefits or impacts, and the extent to which these differences may exacerbate rural inequities and therefore increase latent conflicts.

The field setting, research design and methods used are described in Section 2. Key results from the agronomic and economic assessment are summarized in Section 3, and the livelihood impacts are presented in Section 4. We then seek to link these 'outcomes' to latent conflicts at various levels in the region in Section 5. Conclusions are given in Section 6.

2. Research Design and Methods

Following preliminary desk work, meetings with knowledgeable persons and officials, and field visits, we chose to work in Tamil Nadu state because it had a significant area under Jatropha cultivation and the first initiatives began in 2005.[4] We further focused on Coimbatore (C) and Thiruvannamalai (T) districts because Coimbatore is a centre of Jatropha research, and has several plantations by 'progressive farmers' who follow the recommendations of the Tamil Nadu Agricultural University (TNAU) and Thiruvannamalai is the leading district in terms of area under Jatropha (3876 ha in 2007) (Government of Tamil Nadu, 2007).

Following a preliminary survey, a set of 49 plots owned by 45 households was chosen for doing in-depth interviews with semi-structured questionnaires about yields, economics of production, and livelihoods impacts including 9 in C and 40 in T, with 33 dry land plots and 16 irrigated plots (see Table 1).

Finally, an agronomic assessment was carried out to estimate actual productivity in the field. Since Jatropha requires at least 3 years to start giving consistent economic yields (Paramathma et al., 2007), we attempted to identify plots where the plants were at least 3 years old. However, in spite of an intense search, we could not identify enough plots that met this criterion, and we ended up with 14 plantations (9 in C and 5 in T) older than 2.5 years (see Table 1). We therefore modified the agronomic survey to include some variables that may be proxies for eventual yield: number of branches (primary, secondary and terminal), nuts per plant, nuts per terminal branch, height and canopy diameter.[5] These were compared with yield data based on oral recall from the questionnaire of household survey.

Table 2
Survival rates of Jatropha curcas plantations under different irrigation conditions.

Irrigation	*Plantations sampled*	*% of Jatropha plants surviving*	
		Min–max	*Median*
Rainfed	9	45–99	80
Irrigated	5	90–100	99
Combined	14	45–100	90

Note: Differences between medians were significant at $p<0.01$ using Mann–Whitney *U*-test.

3. Performance of Jatropha at Farm Level

In this section, we address the question of physical productivity of Jatropha plantations and its economic viability.

3.1. Agronomic Performance: Survival, Growth and Yield

We found that overall survival rates were reasonably high (see Table 2).[6] But survival rates in rainfed plots were statistically lower than those in irrigated plots. The average number of nuts per plant was twice as high in irrigated plots as compared to rainfed ones (see Table 3), even though there was high variability within plantations.[7]

Yield data were obtained through oral recall and show that in both 2-year and 3-year old plantations, average yields were higher by a factor of three in irrigated plantations as compared to rainfed ones (see Table 4). The highest yield in 3-year old plantations in rainfed conditions was only 450 kg/ha compared to 750 kg/ha for irrigated conditions. Similarly, the percentage of non-yielding plots was much higher in rainfed conditions (82%) than in irrigated conditions (44%).

The literature suggests that the plant needs water mainly during the first year if rains are irregular, implying that irrigation is required for initial survival only (Paramathma et al., 2007). However, as both yield recalls and the average number of nuts per plant show, the continuous irrigation makes a clear difference between growth and yields in rainfed as compared to irrigated conditions. The continuous irrigation determines the number of fruiting periods per year, which can vary from one to three depending on the level and frequency of irrigation (Tomomatsu and Swallow, 2007). The importance of irrigation for Jatropha is also shown by its high water footprint. The water consumption per unit of energy produced from Jatropha has been reported to be 1.5 times higher than soybean and 5 times higher than ethanol from sugarcane or maize (Gerbens-Leenes et al., 2009b).

[4] Interview with YB Ramakrishna, director of Samagra Vikas, NGO in Karnataka.

[5] These variables were chosen according to expert advice from Dr. Paramathma from Center for Excellence on Biofuels in TNAU.

[6] Although this is partly a selection effect: where Jatropha did not do well, farmers had already removed the crop and so were not picked up in the preliminary survey.

[7] Data on the remaining parameters (nuts per terminal branch, height, canopy diameter, and number of branches) are not presented here for lack of space but their variations are in consonance with variations in survival and nuts per plant.

Table 3
Variation in number of nuts produced per plant by water use (pooling all plant samples across farms and selecting those plants bearing nuts).

Plot type	Plants bearing nuts		
	N	Mean	Std. dev
All	277	33	45
Rainfed	171	28	37
Irrigated	56	49*	60

* Mean is significantly higher at $p<0.014$ in an *F*-test.

Table 4
Yield of Jatropha plots collected in the sampled plantations (from oral recall data).

Age	Water application	Total plots	Yielding plots	Yield (kg/ha)	
				Median	Min–max
2 years	Irrigated	16	8	98	31–500
	Rainfed	33	4	56	25–500
	Total	49	12	73	25–500
3 years	Irrigated	16	1	750	750
	Rainfed	33	2	231	13–450
	Total	49	3	450	13–750

More important than the difference between irrigated and rainfed, is the gap between the yields reported by our sample farmers and those reported in the literature. Globally, reported yields show high variability, ranging from 0.4 to 12 t ha^{-1} $year^{-1}$ (Openshaw, 2000). The age of maturity also varies from 2.5 to 5 years (Achten et al., 2008). In India, agronomists have, however, consistently reported yields in the range of 7500 kg/ha for irrigated plots and 2500 kg/ha under rainfed conditions after 3–5 years under experimental conditions (Prajapati and Prajapati, 2005; Paramathma et al., 2007). A possible bias[8] of the farmers' oral recall is very unlikely to bridge the very large distance between the reported yields and those in the literature. Our figures are also supported by other findings in the literature. Rao (2006), estimated that the average yield of Jatropha seeds in dry lands is unlikely to exceed 1000 kg/ha per year in Maharashtra after the third year. The National Oilseeds and Vegetable Oils Board reported that actual yields without irrigation or fertilizer inputs tend to be well below 2500 kg/ha (NOVOD, 2007, p. 11; Altenburg et al. 2009). Furthermore, BAIF Development Research Foundation has reported that in their 6-year old plantations the highest seed yield under rainfed conditions was about 500 kg/ha in the fifth year. After regular irrigation was introduced in the sixth year the yield was about 1200 kg/ha (Daniel, 2008). Our conclusion about under-performance is therefore consistent with previous findings.

3.2. Economic Performance

The economic analysis, based on survey data from 45 farmers, attempts to assess the economic returns from Jatropha cultivation. Economic costs include initial investments (land preparation and plantation establishment) and the annual maintenance costs (weeding, pruning, fertilizers, pesticides and irrigation).[9] The main factor influencing annual maintenance costs is whether farmer uses diesel pump sets for irrigation or not.[10] The costs and returns for three

Table 5
Comparative results of economic analysis of Jatropha cultivation under different cultivation scenarios.

Economic parameter	Cultivation scenarios		
	Irrigated plot		Rainfed plot (*N* = 23)
	Electric pumpset, own well (*N* = 11)	Diesel pumpset (*N* = 4)	
Field data			
Initial investment Rs/ha[a]	7773	9225	7154
Annual maintenance costs Rs/ha/year[b]	8077	9456	3128
Harvesting costs Rs/ha/year[c]	1645	1645	1588
Annual costs during yielding years Rs/ha/year	9722	11,101	4716
Best price (Rs/kg)	10	10	10
Best yield (kg/ha/year)	750	750	450
Best gross returns (Rs/ha/year)	7500	7500	4500
Best net returns, ignoring initial investments (Rs/ha/year)	*−2222*	*−3601*	*−216*
Total initial investments, if yield starts in year 3[d]	23,927	28,137	13,410
Total initial investments if yield starts in year 5[d]	40,081	47,049	19,666
Plots not yielding at all	5	3	18
Plots which stopped irrigation prematurely[e]	–	3	–
Experimental station data (*Paramathma et al., 2007*)			
Yield at maturation stage (kg/ha)	7500	7500	2500
Gross returns (Rs/ha/year)	75,000	75,000	25,000
Annual costs during yielding years Rs/ha/year[f]	9722	11,101	4716
Net returns, ignoring initial investments (Rs/ha/*year*)	*65,278*	*63,899*	*20,284*

[a] Initial investment figures differ across the two irrigation scenarios simply because of statistical variation. Figures are in Indian rupees (66 INR = 1 € in May 2008).
[b] The operating costs of all types of irrigated plantations were higher than rainfed plantations due to the tendency of farmers to invest more in the application of fertilizers in irrigated plots.
[c] Due to large variation in use of hired labour versus own labour, paid out costs for harvesting varied enormously across farmers. We therefore used an average cost based on total estimated labour input (own and hired) and prevailing wage rates.
[d] Not including any interest burden.
[e] Thereby incurring high initial costs, but low yields.
[f] Assuming same costs as sample farmers, although actually input costs are likely to be higher.

cultivation scenarios (irrigation with electric pump set, irrigation with diesel pump set, and rainfed) assuming the best case yields reported in the previous section, are given in Table 5, along with estimates of what the returns might have been if the yields matched those obtained in the experimental stations.

Our data show that, at current yields, net returns are always going to be negative, even for irrigated farmers (because annual maintenance and harvest costs themselves are higher than the best case gross returns). This is true even if we assume that the best case yields will be reached in year 3 itself, and do not factor in any interest payments, time discounting, or opportunity costs of land. This is primarily because of the extremely low yields. The interest burden on initial investment and the need for subsistence support during the first few years would make the crop even more unviable.

On the other hand, if farmers were to obtain the yields reported by TNAU, the cultivation of Jatropha at the level of costs indicated above might be profitable. Even if one assumes that this yield is reached not in year 3 but in year 5, the last row in Table 5 shows that the total investment of the first 4 years would be recouped in the first yielding year itself. Even if additional costs were involved for family subsistence through the first 4 years, the huge net returns starting year 5 would make it economically viable. However, several caveats

[8] Farmers could report strategically lower or higher yields, in search of government help, compensation or subsidies. Farmers could be reporting a lower or higher yield depending on their perception of what the researcher wishes to listen.
[9] In calculating costs, we only focus on paid out costs, so the net returns include returns to own labour and pure profit. Since small farmers use more family labour, this means the average of input costs for the full sample are lower than those incurred by small farmers, making the economic assessment more favorable to the Jatropha crop.
[10] We also had some farmers who 'rented' wells (8%) or irrigated by hand (14%) rather than pump sets. The cost calculations for these scenarios are not given here, as they do not change the results significantly.

Please cite this article as: Ariza-Montobbio, P., Lele, S., Jatropha plantations for biodiesel in Tamil Nadu, India: Viability, livelihood trade-offs, and latent conflict, Ecological Economics (2010), doi:10.1016/j.ecolecon.2010.05.011

are in order. First, it is likely that to obtain anything like the TNAU yields, farmers would have to provide much higher inputs (primarily fertilizers) which would increase their input costs compromising the final net economic and energy returns.[11] Second, we have not factored in the opportunity cost of land in the above calculations. A single season crop of groundnut provides a net return of about 20,000 Rs/ha under irrigated conditions, which means a foregone return of Rs.40,000/ha/year right from year 1. Under these circumstances, as the last column of the last row shows, Jatropha cultivation may not be profitable for rainfed farmers even under the experimental station yields. Third, this analysis assumes that the prices assumed are actually received and that credit for surviving through the gestation period is not a problem. All of these are major assumptions.

To summarise, under current levels of yields, prices, and cultivation costs, Jatropha cultivation is simply not profitable. A ten-fold increase in irrigated yields (or combination of yield and price) is required to make it profitable, and even then it is not clear that it would exceed the opportunity costs of groundnut cultivation for rainfed farmers. Even if it to become remunerative the capacity to irrigate Jatropha lies only with bigger or better-off farmers. Given the poor agronomic and economic performance of Jatropha, it is not surprising that Jatropha farmers in this region have begun to drop out of this crop. In our own sample, 30% of the plantations had been removed, and 50% are being kept without maintenance. Facing these circumstances, agricultural scientists are trying to develop new high-yielding varieties.[12] If these varieties spread, and if their adoption is combined with increased output or subsidized input prices, they could perhaps make Jatropha economically viable and attractive to farmers. But even in such a scenario, one needs to consider the multi-dimensional livelihood impacts and their distribution across income groups before arriving at a positive assessment. This is precisely, the focus of the next section.

4. Livelihood Trade-offs, and the Distributive Dimension

In this section we investigate differential adoption and wider livelihood impacts and trade-offs across socio-economic classes, using survey data for 45 farmers, identifying changes that are valued outside formal markets. This whole section, thus, deals with the other impacts on livelihood that one should worry about, even if the government was to announce high support prices for Jatropha and the agronomic yields were improved, making cultivation profitable on an average. We investigate then, if in such a scenario Jatropha will work for all farmers, and if it will be pro-poor.

4.1. Differential Adoption and Distribution of Outcomes

We found that there are major biases in who adopts Jatropha and in who can potentially benefit from it. Since we chose the sample only from among all those who had adopted Jatropha, breaking down the sample by landholding category, well-tenancy and caste reveals an interesting pattern.

To begin with, there are clear correlations in resource endowments of the surveyed 45 adopters: large landholders (holding >2 ha) tend to also be well owners (the breakup being 96:4), owning electric pump sets (93:7), and not from a scheduled caste (SC) (96:4).[13] On the other hand, small and marginal landholders (holding ≤2 ha) have an even distribution of well ownership (40:60) and are largely from the SCs (89:11). And when one compares the percentage of large landholders in the sample (56%) with that in the population (30% in C and 6% in T, using district-level data), we see clearly that large landholders are disproportionately represented amongst the adopters today.

Furthermore, given that irrigation is essential for higher yields, it is clear that Jatropha (if and when it becomes remunerative) will preferentially benefit large landholders and non-Scheduled Caste farmers. In our survey, among the 15 who got yields 13 owned electric pumpsets, and only 2 rented a well. The small farmers have mainly seen their plants to get dried or have removed voluntarily the crop due to the high costs of ensuring irrigation. The 71% of the plantations that dried (plants shed their leaves and barely survived) were held by small farmers, mainly in T.

4.2. Food, Fodder and Firewood Trade-offs

The literature on poverty and development has highlighted that rural agrarian households in countries like India tend to have a diversified livelihood, a diverse and inter-linked portfolio of activities and assets (Ellis, 1998). Food crops are grown for self-consumption along with marketed crops. Livestock provide both inputs of dung and draught power and also consume agricultural residue/stubble. Some crops generate residues that substitute for firewood. Household labour also has to be distributed across different activities, and crop choice has complex implications for labour demand. Increase in off-farm work and the seasonal migration of wage labourers (temporary or daily rural–urban commuting) are important components of a livelihood diversification strategy (de Haan, 1999). Many of the activities in the livelihood portfolio are complementary and address different needs of the household; hence they cannot be conceptually aggregated into a single measure of income. Thus, we investigated the trade-offs between different intertwined dimensions of Jatropha cultivators livelihood.

The first dimension of the livelihood impact of Jatropha cultivation is on food self-sufficiency. As Table 6 shows, 82% of the interviewed households were previously cultivating food crops in the plot in which they began Jatropha cultivation; only 18% were converting uncultivated plots or non-food cash crops to Jatropha. This is a very large fraction. Furthermore, in half the sample, the Jatropha plot covered more than 50% of the total landholding of the household, making a major dent into the previous food production of the household.

It is important to note here that groundnut, a major crop in the region, is seen as both a food and a cash crop, as it typically provides the household with a whole year's edible/cooking oil—an expensive commodity otherwise. Four kilograms of groundnuts normally yield a liter of oil, and the annual consumption of a 5-member household is around 50 L. The 42% of the respondents reported that they were significantly affected by the loss of edible oil. Purchasing the 50 L of oil from outside implies 3500 Rs of extra cost per year. It is indeed ironic that while the government promotes Jatropha so as to avoid the

Table 6
Livelihood trade-offs generated by Jatropha plantations.

Livelihood parameter	% of households reporting the change
Households substituting food crops with Jatropha	82
Households affected by edible oil shortage	42
Households affected by fodder shortage	53
Households affected by firewood shortage	20
Households intercropping Jatropha with food crops	44

[11] From a public policy perspective at larger scale than local farmers concern, it must be pointed out that the low performance of the crop reduces the Energy Return on Investment (EROI) (Odum, 1971; Hall et al., 1986).

[12] Direct communications from Dr. Paramathma and observations from interviews with agricultural scientists and field visits to TNAU and Forest College and Research Institute in Coimbatore shows that progress in *J.interregima* and *J.curcas* cross breeding seems to bring a considerable shorter gestation period and therefore less need for credit.

[13] Scheduled castes are Indian population groupings explicitly recognized by the Constitution of India, previously called the "depressed classes."

Please cite this article as: Ariza-Montobbio, P., Lele, S., Jatropha plantations for biodiesel in Tamil Nadu, India: Viability, livelihood trade-offs, and latent conflict, Ecological Economics (2010), doi:10.1016/j.ecolecon.2010.05.011

diversion of precious edible oil to biodiesel manufacturing, Jatropha cultivation itself leads to reduction in oilseed production. Furthermore, wage labourers are willing to accept payment in the form of groundnut—again indicating its importance as a food (protein) source. Thus, loss of the groundnut acreage to Jatropha means more than just loss of income, food and cooking oil, it also means loss of an important medium of exchange, and in effect results in the payment of higher wages in cash. In other cases, Jatropha replaced paddy, sorghum, or vegetables, which were all contributing to the food sovereignty of the household. Where Jatropha replaced pigeon peas or cotton (20% of the cases), the larger livelihood impact (apart from the loss of the food or fiber of the crop) was loss of fuel. An acre of pigeon peas could provide firewood for six months for an average household of five members.

Another trade-off relates to fodder benefits. One acre of paddy or groundnut yields a cart load of paddy straw or groundnut feed for a pair of bullocks for two months. 50% of the sample reported that their access to fodder was definitely reduced by the shift to Jatropha, while the remaining 50% either did not own cattle or were able to obtain fodder or grazing from other lands (private or common). As it is, many parts of rural India have been affected by fodder shortage—also called the 'other food crisis' (Narain, 2005)—and the cultivation of Jatropha might exacerbate the crisis. While the market value of the fodder provided by the crop that Jatropha replaces can be factored into a marginal economic assessment, the non-marginal effects of large-scale Jatropha cultivation on fodder availability and prices cannot be easily factored in.

Finally, Jatropha cultivation also leads to reduction of crop diversity. Pre-Jatropha, farmers typically followed one of three rotations: between groundnut and short-term rainfed crops (cereals and pulses) (63% of sample farmers), between groundnut, rice and pulses (13%), vegetables and other fruit crops (6%). Although 44% of the households decided to intercrop between Jatropha the first year, the next 2 years, after the crops has grown tall enough, all farmers had largely a monoculture. Diversity of crops buffers the household against vagaries of climate, pest and other problems. Cultivation of Jatropha as a perennial monocrop would reduce the sustainability of the household's livelihood.

For all the different dimensions of livelihood impact discussed above, it is important to note that there are differences in impact across socio-economic classes. For instance, relatively large farmers devoted only the 35% of their land to Jatropha cultivation (in average Jatropha plots of 1.6 ha), as compared to smaller farmers where Jatropha occupied 75% of their landholding (in average Jatropha plots of 0.6 ha). The food sovereignty impacts of shifting to Jatropha would therefore be sharper for the smaller farmers. Similarly, being an SC farmer increased the likelihood of the household facing fuel-Jatropha trade-offs[14] because these households tend to have a more subsistence oriented rationality in their plot cultivation.

4.3. Changes in Employment and Migration

One-third of the households reported increasing their off-farm activities as wage labourers during the period of Jatropha cultivation. The increase in off-farm activities was more prevalent amongst small and marginal farmers.[15] As stated by some of the interviewees, the farmers were unable, for a lack of reliable knowledge, to assess how many days of additional off-farm work they needed after the adoption of Jatropha. In other words, the uncertainty about Jatropha's performance and labour requirement meant that farmers decided to engage more in off-farm activities even if they could not get high value long-term contracts, only short-term daily wage work. This strategy could help to achieve enough income in case of Jatropha failure.

As regards seasonal migration, we observed that, normally, after the agricultural season (October–January), the labourers (mostly landless, small and marginal farmers) used to migrate to the nearby cities (Chennai, Tiruppur, Bangalore…) or to other rural areas of neighboring Kerala state to work as daily wage labourers. Previously, when they were planting short-term crops they had to stay in the village to guard and irrigate the crops. Now, after Jatropha was introduced, in case of total substitution they were leaving the management of the crop especially in the second and third year, staying in the towns for longer periods.

It is possible that the low labour requirement of Jatropha, if accompanied by high returns from it, will lead to a double dividend through increased returns from off-farm work. But as of now, the increased income (coming from low-value work) is probably used for compensating for the loss on other livelihood dimensions (food, fuel, fodder). However, from a "strong sustainability" approach, all trade-offs in several livelihood dimensions cannot be necessarily reduced to a single measure. The reduction of crop, income and food sources diversity could lead small farmers to be more vulnerable to changes and fluctuations.

5. Land and Water Uses and Latent Conflicts

Ecological distribution conflicts (Martínez-Alier, 2002) are usually in the form of tussles between the state or corporate entities and local communities, and take the form of public protests, movements, or agitations. It is possible, however, to think about environmental conflicts as being multi-level and more latent (Dahrendorf, 1958). Conflicts may exist not just with a company but also within a community and within a household. They may take the form not of open agitation as much as hidden tensions. We observe a mixture of tension and open conflict at multiple levels in the case of Jatropha cultivation in Tamil Nadu.

Jatropha plantations in Thiruvannamalai and Coimbatore districts have failed to perform anywhere close to the hype and expectations raised by government agencies and private companies. To add insult to injury, companies have now abandoned the buyback contracts they had signed with the Jatropha farmers. Moreover, as seen above, Jatropha cultivation has different impacts for different sections of farmers. All these have led to various forms of tension and conflict.

At one level, some tensions and conflicts have emerged within households over what should be the response after the failure of Jatropha. Two joint families reportedly got trapped in a conflict over whether they should split the landholding in different parts for fathers and sons, thereby allowing each to decide for themselves about Jatropha cultivation, or should resort to the permanent migration of some disgruntled member.

Much greater conflict ensued between farmers and local promoters of Jatropha. Companies and NGOs promoting Jatropha contacted key individuals in the villages for helping them. These 'promoters' agreed to do not so much for money as for social recognition. But as soon as the crop failed, social recognition turned into scorn, as they were seen by the adopters as responsible for the loss in livelihoods.[16]

At a third level, conflict is brewing between farmers (including promoters) and the private companies who had promoted Jatropha cultivation. The companies did not abide by promises of giving special loans for getting improved water infrastructure, income complements

[14] In a logit regression with fuel-Jatropha trade-off reported (Yes/No) as the dependent variable, schedule caste was a significant independent variable ($p<0.055$).

[15] In a logit regression with increasing off-farm activities (Yes/No) as the dependent variable, the landholding (being small or marginal farmer (Yes/No)) was a significant independent variable ($p<0.041$).

[16] In Alattur village, in Thiruvannamalai, a handicapped villager was contacted by a woman who facilitated Women Self Help Groups of an NGO called SCOPE. He was convinced to plant Jatropha due to its low labour requirements. He helped the woman to promote Jatropha at village level. After the failure of Jatropha he has been scorned by several villagers than even beat him in some occasion.

during gestation period (goats rearing or apiculture), and buying the produce at remunerative prices. Farmers responded both formally and informally. Formally, they lodged a collective protest at the Thiruvannamalai District Collectorate against D1 Mohan Bio Oils Ltd. But it generated no response, either from the government or from the company. Informally, there has been tension with local company staff posted in the region. But this anger could not find an outlet, because company staff was comprised of other villagers from the region. They were hired temporarily and dropped off by companies when they abandoned their contracts. Indeed, some villagers employed by the companies did not get full wages from the companies either.

Finally, there is the potential conflict that may follow if Jatropha actually becomes remunerative and therefore widespread adoption takes place. Irrigation remains the key input for a profitable Jatropha cultivation. This has two implications. First, it automatically excludes the poorest farmers, the rainfed cultivators. Second, it increases demand for irrigation water in a region where water is already scarce. Janakarajan and Moench (2006) have argued that degradation of groundwater resource base through over-extraction and pollution contributes to inequity, conflicts, competition and, above all, to indebtedness and poverty. The declining water tables, further promoted by policies providing free or highly subsidized electricity, force farmers to competitively dig deeper wells undermining the collective effort to manage common rain water harvesting systems (Vaidyanathan, 2001; Reyes-García et al., in press). Although tank water property rights are unequal as well, groundwater extraction is in open access leading to overexploitation compromising intra and intergenerational equity. Besides, there are informal markets between well-owning farmers and non-well-owning farmers and, as water becomes increasingly scarce, dependency relations intensify with purchasers in an ever-weaker bargaining position. Jatropha, although presented as a crop that can be pro-poor and respond to water scarcity, is more part of the problem than the solution. Jatropha-induced conflicts at the household and village level can go hand-in-hand with the already existing conflicts over water access due to the crop water requirements and the differential nature of livelihood impacts.

6. Conclusions

The supporters of Jatropha have argued that it succeeds without irrigation and therefore does not compete for water or displace food production from prime agricultural land (The Economist, 2008). Our results clearly contradict these simplistic claims. Not only does irrigation make a big difference to yields, but even with irrigation the yields are so much lower than those reported from experimental plots. The economic returns were negative. Not surprisingly, we found that 30% of our sample farmers had already removed the crop. Our results provide reasons for understanding the global investors' disappointment with Jatropha (Sanderson, 2009).

Jatropha has entailed multi-dimensional livelihood impacts for farmers that were unevenly distributed across classes. They would be still in place even if some new high-yielding varieties spread with increased output or subsidized input prices, which would make Jatropha economically viable and attractive to farmers. A mono-crop pattern of Jatropha entails increased specialization that generates food, fodder and firewood trade-offs reducing household self-sufficiency as well as net income. Besides, there are changes in livelihood strategies, such as increased off-farm labour, circular migration and increase of informal credit but their implications are unclear. These circumstances are likely to threaten the multi-functionality of agro-ecosystems increasing external dependency of households, compromising their ability to cope with stress. Perhaps most important, the capacity to irrigate is lower and livelihood impacts sharper for small and marginal farmers.

All these circumstances, assuming a weak sustainability approach, can be compensated for by high economic returns. However, in the case of Jatropha, even in the most optimistic performance scenario, the returns come only after no less than 3 years of gestation period. The crop imposes a significant need for long-term credit, which smallholders cannot meet. There is little hope then that poor rainfed farmers will adopt Jatropha, if they have complete information on the agronomic performance, irrigation demand and credit requirements of the crop. Only large landholders and socially higher caste farmers with access to irrigation can hope to generate positive returns. While the failure of Jatropha has currently created conflicts between farmers, biodiesel companies and their promoters within the villages, the water demand of Jatropha and the uneven distribution of the gains from and livelihood impacts of the crop can trigger or exacerbate the conflicts over water and resource access between farmers.

In this paper, we focused on the individual farmer's perspective. But it is worth pointing out that from a larger public policy perspective, support for Jatropha seems also misplaced. The energy return on investment (EROI) is fairly low (Lam et al., 2009), the conversion of food crops to Jatropha has negative public welfare implications, and the competitive demand for water has negative sustainability implications for society. The fraction of the growing energy demand that can be met at the end of this would be very small. Finally, as shown above, Jatropha is not pro-poor. Continued pursuit of such policies by the state is therefore highly questionable.

The growth of exosomatic energy throughput beyond a certain point makes society enter in a clear contradiction (nationally and/or internationally) between energy use and equity (Illich, 1974). The rural poor can be (un)consciously pushed aside due to the elite's dream of achieving a so called clean energy source, such as biofuels, without changing the current paradigm of development.

Acknowledgements

We would like to thank all the people interviewed, especially the farmers who taught us what cannot be found in books and papers. We are especially grateful Ignatius Prabhakar for his help and insights in our fieldwork, to Anand, Yokesh and Sreenivasan for their translation, to Dr. Paramathma for his suggestions in the agronomic assessment and to David Chackrawarthy for his unconditional help whenever and wherever. We are grateful to Joan Martínez-Alier, Jesús Ramos Martín and Giorgos Kallis for their suggestions and to Francisco Zorondo, Vicky Reyes and Ivana Logar for revision and help in data processing. The first author would also like to thank Centre for Interdisciplinary Studies in Environment and Development for hosting and befriending him during the research in India, and research project SEJ2006-15219. The second author's contribution to this study is supported by an institutional grant from the Ford Foundation.

References

Achten, W.M.J., Verchot, L., Franken, Y.J., Mathijs, E., Singh, V.P., Aerts, R., Muys, B., 2008. Jatropha bio-diesel production and use. Biomass and Bioenergy 32, 1063–1084.

Altenburg, T., Dietz, H., Hahl, M., Nikolidakis, N., Rosendahl, C., Seelige, K., 2009. Biodiesel in India, Value Chain Organisation and Policy Options for Rural Development. Studies Report N. 43. German Development Institute, Bonn (Available online: http://www.die-gdi.de/CMS-Homepage/openwebcms3.nsf/%28ynDK_contentByKey%29/ANES-7PKDWS/$FILE/Studies%2043.2009.pdf).

Clancy, J.S., 2008. Are biofuels pro-poor? Assessing the evidence. The European Journal of Development Research 20, 416.

Dahrendorf, R., 1958. Towards a theory of social conflict. Journal of Conflict Resolution 2, 170–183.

Daniel, J.N., 2008. Jatropha Oilseed Production: A Realistic Approach. BAIF Development Research Foundation. (Available Online: http://www.baif.org.in/aspx_pages/pdf/Agroforesty/MEDA.pdf).

de Haan, A., 1999. Livelihoods and poverty: the role of migration — a critical review of the migration literature. Journal of Development Studies 36, 1.

DeFraiture, C., Berndes, G., 2009. Biofuels and Water. In: Howarth, R.W., Bringezu, S. (Eds.), Biofuels: Environmental Consequences and Interactions with Changing Land Use. Proceedings of the Scientific Committee on Problems of the Environment

(SCOPE) International Biofuels Project Rapid Assessment, 22–25 September 2008, Gummersbach Germany, pp. 139–153.

Ellis, F., 1998. Household strategies and rural livelihood diversification. Journal of Development Studies 35, 1.

Ewing, M., Msangi, S., 2009. Biofuels production in developing countries: assessing tradeoffs in welfare and food security. Environmental Science & Policy 12, 520–528.

Fargione, J., Hill, J., Tilman, D., Polasky, S., Hawthorne, P., 2008. Land clearing and the biofuel carbon debt. Science 319, 1235–1236.

Field, C.B., Campbell, J.E., Lobell, D.B., 2008. Biomass energy: the scale of the potential resource. Trends in Ecology & Evolution 23, 65–72.

Francis, G., Edinger, R., 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 29, 12–24.

Gerbens-Leenes, P.W., Hoekstra, A.Y., van der Meer, T., 2009a. The water footprint of energy from biomass: a quantitative assessment and consequences of an increasing share of bio-energy in energy supply. Ecological Economics 68, 1052–1060.

Gerbens-Leenes, W., Hoekstra, A.Y., van der Meer, T.H., 2009b. The water footprint of bioenergy. Proceedings of the National Academy of Sciences 106, 10,219–10,223.

Giampietro, M., Mayumi, K., 2009. The Biofuel Delusion. The Fallacy of Large-scale Agro-biofuel Production. Earthscan, London.

Giampietro, M., Ulgiati, S., Pimentel, D., 1997. Feasibility of large-scale biofuel production: does an enlargement of scale change the picture? Bioscience 47, 587–600.

Giampietro, M., Mayumi, K., Ramos-Martin, J., 2006. Can biofuels replace fossil energy fuels? A multi-scale integrated analysis based on the concept of societal and ecosystem metabolism: part 1. International Journal of Transdisciplinary Research 1, 51–87.

Government of India, 2003. Report of the Committee on Development of Bio-Fuel.

Government of India, 2009. National Policy on Biofuels. Ministry of New & Renewable Energy, New Delhi.

Government of Tamil Nadu, 2007. Status Report on Promotion of Jatropha Cultivation in Tamil Nadu. Agriculture Department, Chennai.

GRAIN, 2008. Agrofuels in India, private unlimited. Seedling (April 2008) p. 15-23. Available on line at: http://www.grain.org/seedling/?type=72.

Haberl, H., Schulz, N.B., Plutzar, C., Erb, K.H., Krausmann, F., Loibl, W., Moser, D., Sauberer, N., Weisz, H., Zechmeister, H.G., Zulka, P., 2004. Human appropriation of net primary production and species diversity in agricultural landscapes. Agriculture, Ecosystems & Environment 102, 213–218.

Hall, C.A.S., Cleveland, C.J., Kaufmann, R., 1986. Energy and Resource Quality: The Ecology of the Economic Process. Wiley-Interscience, New York.

Howarth, R.W., Bringezu, S., Bekunda, M., Fraiture, C.d., Maene, L., Martinelli, L.A., Sala, O.E., 2009. Rapid assessment on Biofuels and Environment: Overview and Key Findings. In: Howarth, R.W., Bringezu, S. (Eds.), Biofuels: Environmental Consequences and Interactions with Changing Land Use. Proceedings of the Scientific Committee on Problems of the Environment (SCOPE) International Biofuels Project Rapid Assessment, 22–25 September 2008, Gummersbach Germany, pp. 1–13.

ICRISAT, 2007. Pro-Poor Biofuels Outlook for Asia and Africa: ICRISAT's Perspective. (Hyderabad).

Illich, I., 1974. Energy and Equity. Calder & Boyars, London.

International Energy Agency, 2007. World Energy Outlook 2007. Executive Summary. China and India Insights.

Janakarajan, S., Moench, M., 2006. Are wells a potential threat to farmers' wellbeing? Case of deteriorating groundwater irrigation in Tamil Nadu. Economic and Political Weekly 41, 3977–3986.

Lam, M.K., Lee, K.T., Mohamed, A.R., 2009. Life cycle assessment for the production of biodiesel: a case study in Malaysia for palm oil versus jatropha oil. Biofuels, Bioproducts and Biorefining 3, 601–612.

Martínez-Alier, J., 2002. The Environmentalism of the Poor: A Study of Ecological Conflicts and Valuation. Edward Elgar, Cheltenham.

Mitchell, D., 2008. A Note on Rising Food Prices. Development Prospects Group, World Bank, Policy Research Working Paper Number 4682. . (July 2008).

Moraa, V., Iiyama, M., Nzuma, J., Munster, C., Mbatia, O.L.E., Hunsberger, C., 2009. Food or Jatropha curcas for Biodiesel Production? A Cost Benefit Analysis in Kwale District. DSA Paper.

Narain, S., 2005. The Other Food Crisis. Down to Earth. (December 15th).

National Oilseeds and Vegetable Oils Development Board (NOVOD), 2007. Jatropha. An Alternate Source for Biodiesel, New Delhi. (Available online: http://www.novod-board.com/Jatropha-english.pdf) .

Odum, H.T., 1971. Energy, Power and Society. Wiley-Interscience, New York.

Openshaw, K., 2000. A review of Jatropha curcas: an oil plant of unfulfilled promise. Biomass and Bioenergy 19, 1–15.

Paramathma, M., Venkatachalam, P., Sampathrajan, A., Balakrishnan, A., Jude Sudhakar, R., Parthiban, K.T., Subramanian, P., Kulanthaisamy, S., 2007. Cultivation of Jatropha and Biodiesel Production. Professor and Nodal Officer, Center of Excellence in Biofuels. Agricultural Engineering college & Resarch Institute, Tamil Nadu Agricultural University, Coimbatore. (180 pp).

Planning Comission, 2006. Integrated Energy Policy. Govermnent of India, New Delhi.

Prajapati, N.D., Prajapati, T., 2005. A Hand Book of Jatropha curcas Linn. (Physic Nut). Asian Medical Plants & Health Care Trust, Jodhpur, Rajasthan, India.

Rajagopal, D., 2008. Implications of India's biofuel policies for food, water and the poor. Water Policy 10, 95–106.

Rao, V.R., 2006. The *Jatropha* Hype: Promise and Performance. In: Singh, B., Swaminathan, R., Ponraj, V. (Eds.), Biodiesel Conference Towards Energy Independence — Focus on *Jatropha*. Papers presented at the Conference Rashtrapati Nilayam, Bolaram, Hyderabad on 9–10 June, 2006, pp. 16–19.

Reyes-García V., Aubriot O., Ariza-Montobbio P., Galan-del-Castillo E., Serrano T. and Martínez-Alier J., in press. Local perception and uses of the multifunctionality of water tanks. A case study in two villages of Tamil Nadu, South India. Society and Natural Resources.

Russi, D., 2008. An integrated assessment of a large-scale biodiesel production in Italy: killing several birds with one stone? Energy Policy 36, 1169–1180.

Sanderson, 2009. Wonder weed plans fail to flourish. Nature 461, 328–329 doi:10.1038/461328a (September. Available online: http://www.nature.com/news/2009/090916/full/461328a.html).

The Economist, 2008. Biofuels in India. Power plants. The slow ripening of India's biofuel industry. The Economist September 18th 2008. Available on line at: http://www.economist.com/businessfinance/displaystory.cfm?story_id=E1_TNNSDJSQ.

Tilman, D., Socolow, R., Foley, J.A., Hill, J., Larson, E., Lynd, L., Pacala, S., Reilly, J., Searchinger, T., Somerville, C., Williams, R., 2009. Beneficial biofuels—the food, energy, and environment trilemma. Science 325, 270–271.

Tomomatsu, Y., Swallow, B., 2007. Jatropha curcas Biodiesel Production in Kenya Economics and Potential Value Chain Development for Smallholder Farmers. Working Paper 54. World Agroforestry Centre, Nairobi.

UNESDA, 2007. Small-Scale Production and Use of Liquid Biofuels in Sub-Saharan Africa: Perspectives for Sustainable Development. Background Paper 2. United Nations Department of Economic and Social Affairs Energy and Transport Branch. Division for Sustainable Development, New York.

Vaidyanathan, A., 2001. Tanks of South India. Center for Science and Environment, New Delhi.

Vitousek, P.M., Ehrlich, P.R., Ehrlich, A.H., Matson, P.A., 1986. Human appropriation of the products of photosynthesis. Bioscience 36, 368–373.

Please cite this article as: Ariza-Montobbio, P., Lele, S., Jatropha plantations for biodiesel in Tamil Nadu, India: Viability, livelihood trade-offs, and latent conflict, Ecological Economics (2010), doi:10.1016/j.ecolecon.2010.05.011