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Performance of Jatropha biodiesel production and its environmental and socio-economic impacts

- A case study in Southern India

Master of Science Thesis in the Master Degree Programme Industrial Ecology

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Göteborg, Sweden, 2010

Report No. FRT 2010:06

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Göteborg, Sweden 2010

Foreword

After experiencing the genuine Indian culture, tremendous heat, great hospitality, nerve-wrecking traffic, delicious food and inspiring encounters with interesting people we are now putting the last amount of blood, sweat and tears into this Master's thesis.

Frustration and confusion were our frequent companions when we faced challenges such as language difficulties, adapting to a new culture, and dealing with the bureaucratic procedures within the Indian government agencies. The experience was very rewarding, helping us see things from different perspectives. Hopefully our work will make a contribution to the knowledge regarding cultivation of Jatropha.

Jatropha, the crop, has been with us since we wrote the first sentence for the Minor Field Study scholarship application and has more or less been the only consistent factor during the project while everything around it has changed: the purpose of the study, the geographical area for the study and our perception of its potential. So, we would like to start our list of acknowledgements by thanking Jatropha: Thank you.

We would also like to thank everyone who made our field study in Southern India possible, starting with Lakshmi Gopakumar who was our project colleague as well as our teacher of Indian culture and customs. We would like to direct our gratitude to Professor N.H. Ravindranath who agreed to be our supervisor in India, for assisting us in turning our research idea into a feasible project. Our gratitude also goes out to the staff at the Centre for Sustainable Technologies, Indian Institute of Science in Bangalore, for helping us with practical arrangements, especially to G.T. Hegde who participated in the field study in Andhra Pradesh.

During our field study in Andhra Pradesh and Tamil Nadu we had help from representatives from two NGOs, Centre for Human Resource Development and Green Youth Foundation, and we would like to thank everyone who assisted us by translating, guiding, and driving.

Our thanks go to our three supervisors Göran Berndes, Madelene Ostwald, and Stefan Wirsenius, at the Department of Energy and Environment at Chalmers University of Technology, for contributing their time and expertise.

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Abstract

The increased demand for renewable energy sources and India's need to secure its energy supply have spurred interest in development of biofuel production in India. Expectations have been high for the production of biodiesel from the oil-crop Jatropha. Jatropha is promoted as a drought- and pest-resistant crop, with the potential to grow on degraded soil with a low amount of inputs. These characteristics encourage hope for positive environmental and socio-economic impacts from Jatropha biodiesel production. In 2003 a large-scale government programme was launched for promotion and implementation of Jatropha cultivation and biodiesel production. To gain more information on Jatropha performance the Indian Institute of Science performed a field study in Southern India in 2005-06, conducting interviews with Jatropha farmers and measurements of their plantations.

The current study is a follow-up to the previous study. The purpose is to explore the performance of Jatropha biodiesel production in Southern India, to indentify motivational factors for continued Jatropha cultivation, and to assess environmental and socio-economic impacts of the Jatropha biodiesel production. For this purpose, 106 farmers who have or have had Jatropha plantations were visited and interviewed regarding their opinion of Jatropha cultivation and existing plantations were assessed.

The study finds that 85 percent of the Jatropha farmers have discontinued cultivation of Jatropha. The main barriers to continued cultivation derive from ecological problems and economic losses. The Jatropha characteristics were overrated, and the plantations failed to provide income to the farmer. Problems in the development and execution of the government implementation of the Jatropha programme were also identified as barriers. The farmers experienced a lack of support from involved authorities. A common factor for the farmers who have continued Jatropha cultivation is that they have the economic means to maintain non-profitable plantations. As the Jatropha programme was not as successful as expected, the expected positive environmental and socio-economic impacts have not been realized.

Keywords: Jatropha, biodiesel, energy, India, rural development

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List of Abbreviations

CLDP – Comprehensive Land Development Programme

CPRs – Common Property Resources

DPAP – Drought Prone Area Development Programme

DRDA – District Rural Development Agency

DWMA – District Water Management Agency

GBH – Girth at Breast Height

GHG – Greenhouse Gas

IPCC – Intergovernmental Panel on Climate Change

IFEU - Institute for Energy and Environmental Research in Heidelberg, Germany

IWDP – Integrated Wasteland Development Programme

NGO – Non-governmental Organization

NRAA - National Rainfed Area Authority

NREGA – National Rural Employment Guarantee Act

NREGP – National Rural Employment Guarantee Programme

RSAD – Rain Shadow Areas Development

SHGs – Self-Help Group

Description of institutional agencies and programmes

CLDP – Comprehensive Land Development Programme

Government programme where the objectives are to enhance and diversify the livelihood options, and to improve productivity to secure food and fuel supply, for poor farmers living on land assigned to them by the government or farmers owning land in poor tribal regions (Rural Department 2009).

Collectorate

District government office where the most powerful district official, the District Collector, is housing.

DPAP – Drought Prone Areas Programme

Government programme aiming at development of drought prone areas and mitigation of negative effect from drought on agricultural production, land productivity, water and human resources (NIRD 2009).

DRDA – District Rural Development Agency

The organ that at district level manages and monitors the implementation of the anti-poverty programmes of the Ministry of Rural Development. (DRDA 2007)

DWMA – District Water Management Agency

Government agency that at district level manages development of human and natural resources on a watershed basis (RSAD 2006b).

IWDP – Integrated Wasteland Development Programme

Government programme aiming at improved productivity of wasteland and thereby improve livelihoods of the rural poor who own these lands (Angul District 2008).

NRAA - National Rainfed Area Authority

Government authority under the Ministry of Agriculture that promotes a participatory development process of rainfed areas (NRAA 2010).

NREGA – National Rural Employment Guarantee Act

Government act that seeks to provide enhanced livelihood security, by guaranteeing at least 100 days of paid work every year to rural households.(NREGS-AP 2006).

NREGP – National Rural Employment Guarantee Programme

A government programme under NREGA. NREGP works for water conservation and drought proofing by promotion of afforestation and special focus in the plantations are on bio-diesel trees such as Jatropha and Pongamia. (NREGS-AP 2006)

RSAD – Rain Shadow Areas Development Department

Government department in Andhra Pradesh that formulates, implements and monitors programmes for agricultural development in rain deficient areas (RSAD 2005).

Watershed programme

Government programme aiming at conservation and management of water resources by draining of water to common points (ICAR 2008).

1. Introduction

The initial chapter gives the background to the study, presents the purpose, and outlines the research questions in focus. The chapter also outlines the method and limitations of the study.

1.1. Background

India has developed rapidly during the past decades, reducing the percentage of the population living below the poverty line from 55 percent in 1973 to 21 percent in the late 1990s. However, 250 million Indians still live in poverty and are dependent on continued development to raise their standard of living. (IARI 2010) In order to fight poverty and enhance livelihoods in developing countries the supply of food and energy must be secured; the population needs food for sustenance, and access to modern energy sources is necessary in order to achieve both economic growth and sufficient social and public services.

India depends on import of fossil fuels to satisfy energy demand, and with population growth and economic development the demand will continue to increase. (Siddharth 2009) Fossil fuels are finite energy resources, and as the amount of new supplies found is decreasing, the resources will eventually be exhausted. Furthermore, the use of fossil fuels has a severe impact on climate change. Increased fossil fuel use thus conflicts with the increasing global pressure to reduce environmental impact and mitigate climate change (Planning Commission 2003).

In combination with the increasing global demand for renewable energy forms, the need to secure energy supply in developing countries has created a demand for biomass energy, such as biofuels (Siddharth 2009). One of the most common biofuel energy systems is production of biodiesel through transesterification of non-petroleum based oils. Biodiesel can be used in unmodified diesel engines, either alone or blended with conventional petrodiesels (Achten 2008). For developing countries, production of biodiesels could represent a way to achieve economic growth by increasing and securing energy supply, but also by creating job opportunities and as a source of income for the farmers involved.

However, the advantages of biofuels come with disadvantages. One of the problems arising from the increasing demand for biodiesel is competition between the production of biodiesel crops and the production of food crops. It is argued that direct competition with food commodities can be avoided through the use of non-edible crops as biodiesel feedstock (Biswas 2009). Still, if cultivation of biofuel crops leads to higher incomes, farmers will choose to produce biofuels instead of food. This decrease in food production will result in an increase in food prices.

One of the crops that have been considered among the most promising for production of biodiesel is Jatropha. Its promoters argue that it does not compete directly with food production since the whole plant is toxic and hence non-edible. More importantly, the potential of Jatropha to grow on degraded soil and its resistance to drought and pests enable cultivation on land that is not suitable for food production. (Biswas 2009) The characteristics of Jatropha have raised expectations for positive environmental and socio-economic impacts from biodiesel production, and a large-scale government programme was launched in 2003 for promotion and implementation of biodiesel production from Jatropha (Planning Commission 2003). To gain more information on the performance of Jatropha plantations and impacts of the biodiesel production the Indian Institute of Science in Bangalore performed a field study together with Jatropha farmers in 2005-06, when the plantations were still at an early stage.

1.2. Purpose and research questions

The purpose of the study is to describe the Jatropha characteristics and production system in general, and to explore the performance of Jatropha biodiesel production under prevailing energy and agricultural conditions in Southern India. The focus is to identify motivational factors for continuation and termination of Jatropha cultivation and to assess environmental and socio-economic impacts of the Jatropha biodiesel production.

The objective of this study is to provide answers to the following research questions:

- To what extent has Jatropha been able to meet the high expectations put on its performance as a biodiesel crop?
- What motivational factors act as drivers and barriers to continued Jatropha cultivation for farmers?
- What are the environmental and socio-economic impacts of Jatropha biodiesel production?

1.3. Method overview

The study is a follow-up to a study performed in 2005-06 at the Indian Institute of Science in Bangalore, India. During the former study 139 Jatropha farmers in Southern India were interviewed in person regarding the status of their plantations and the impact of Jatropha on their livelihood.

The current study starts with a literature review of studies and reports on Jatropha characteristics and the energy and agricultural conditions in India. The literature review was followed by a field study where the farmers from the former study were re-visited and interviewed, and their Jatropha fields were assessed, in order to gain knowledge about the current conditions of their plantations and about the socio-economic and environmental impact of Jatropha production.

1.4. Limitations

The farmers targeted in the current study are the same farmers interviewed five years ago. Additional farmers were added to the sample, but the study is geographically limited to farmers living in the states of Andhra Pradesh and Tamil Nadu. Not all areas within these states are covered, since the focus has been the districts included in the previous study. Except for Andhra Pradesh and Tamil Nadu, the state Chattisgarh was part of the previous study but has not been included in the current study, mainly because no private farmers were visited within that state and because of time constraints.

Regarding the impacts of Jatropha biodiesel this study does not consider the use phase of the biodiesel.

1.5.Structure of thesis

Chapter 1. Introduction
The initial chapter gives the background to the study, presents the purpose, and outlines the research questions in focus. The chapter also outlines the method and limitations of the study.

Chapter 2. Jatropha production system
The aim of the chapter is to describe the whole system of Jatropha biodiesel production, from seed to biodiesel. The characteristics of the Jatropha plant are described together with its ecologic preferences and cultivation practices, followed by the process of turning the seed into biodiesel. The chapter concludes with the environmental impacts of the described production system.

Chapter 3. The Indian context
This chapter presents background information on policies on biofuels and the existing agricultural system to provide context regarding Jatropha cultivation in southern India.

Chapter 4. Research methodology
This chapter presents the applied research process and strategy along with the method for data collection, description of the data, sampling method, and method for interpretation of results. The validity and reliability of the results generated by the strategies and methods used are discussed as are ethical considerations.

Chapter 5. Description of the empirical study
The chapter provides a short description of the previous study, and an overview of the studied states and their implementation of the Jatropha programme. Further it presents an overview of the field study.

Chapter 6. Results
This chapter presents the results from the field study. First the chapter provides background information on the respondents and how many of the respondents have continued or discontinued cultivation of Jatropha, continuing with a description of how Jatropha was introduced. Details regarding the Jatropha plantations are given, followed by an account of inputs to and outputs from the plantations. Drivers and barriers to continued cultivation of Jatropha and stated advantages and disadvantages are presented. The chapter concludes with a presentation of the results from biomass measurements.

Chapter 7. Interpretation of results
This chapter interprets the results with the intention to address the purpose and research questions asked in the first chapter. It analyses the drivers and barriers to continuation of Jatropha cultivation and the impacts on the environment and socio-economic development. The chapter concludes with a comparison of Jatropha's performance in Andhra Pradesh and Tamil Nadu.

Chapter 8. Conclusions
The conclusions of the study answer the research questions.

Chapter 9. Discussion

During this project interesting issues in need of further research were encountered. This chapter discusses the main topics among these.

2. Jatropha production system

The aim of the chapter is to describe the whole system of Jatropha biodiesel production, from seed to biodiesel. The characteristics of the Jatropha plant are described together with its ecologic preferences and cultivation practices, followed by the process of turning the seed into biodiesel. The chapter concludes with the environmental impacts of the described production system.

2.1. Biology of Jatropha

Jatropha Curcas L., in this report referred to only as Jatropha, is a small tree or large bush belonging to the Euphorbiaceae family (Achten 2008). See Figure 1 for examples of two Jatropha plants. Normally the plant reaches a height of three to five meters but can reach up to eight to ten meters when grown under favourable conditions. It has a life expectancy of up to 50 years, maturing after four to five years, and grows into different shapes, with one stem with no or few branches, or with branches growing from below. The plant initially develops one central deep tap root and four lateral roots. (Kumar 2008) The tap root can stabilize the soil and prevent landslides while the more shallow roots are assumed to prevent soil erosion caused by wind and water. (Achten 2008)

Figure 1. Examples of two Jatropha plants in Southern India

Jatropha is a plant of deciduous type and sheds its leaves during dry season and also under stressful conditions (Fact Foundation 2009a). The leaves are green, smooth, 4-6 lobed and 10-15 cm in width and length (Achten 2008). The plant has separate male and female flowers which are organized in clusters, inflorescences. The plant carries more male than female flowers, the male-to-female ratio is 29:1. Brittaine and Lutaladio (2010) report that the ratio may decrease with plant age implying increased fruiting capacity with age. Flowering normally occurs once a year, during rainy season, but in permanently humid areas or under irrigation it flowers throughout the whole year. (Kumar 2008) See Figure 2 for examples of a Jatropha leaf and Jatropha flower.

Figure 2. Examples of Jatropha leaves and flower

After pollination by insects, mainly honey bees, approximately ten green fruits having an ellipsoidal shape are formed by each inflorescence (Kumar 2008). Each fruit is about 40 mm long and contains three seeds. Occasionally a fruit can contain four to five seeds. (Fact Foundation 2009a) It takes three to four months after the flowering for the seeds to mature. The seeds are black, measuring on average 18 mm in length, 12 mm in width, and 10 mm in thickness (Fact Foundation 2009a). The seeds weigh between 0.5 and 0.8 grams and the average number of seeds per kilo is 1375 seeds (Kumar and Sharma 2008). The seed yield per tree is reported to range from 0.2 to 2.0 kilos per year (Brittaine 2010). The seed's shell and inner kernel account for on average 37 and 63 percent of the total weight, respectively. Oil content of the seeds range from 32 to 40 percent; the average is 34 percent. The seed contains toxins, such as phorbol esters, curcin, trypsin inhibitors, lectins, and phytates, which render the seeds, oil, and seed cake non-edible if not detoxified. (Achten 2008) See Figure 3 for examples of fresh fruit and seeds.

Figure 3. Examples of fresh fruits and seeds

2.2.Geographical distribution and ecologic preferences of Jatropha

Jatropha grows in tropical areas all around the world. Its exact point of origin is still unknown, but located in the Central America and Mexico area. The plant was probably brought to Africa and Asia by Portuguese seafarers via Cape Verde, which is also where its first commercial use was reported during the first half of 20th century. Lisbon and Marseille imported the produced seed to extract oil for soap production, a significant contribution to the exporting country's economy. Today Jatropha is cultivated in Central and South America, South-East Asia, India and Africa. (Heller 1996)

According to current knowledge, Jatropha is an easily established, drought-resistant plant, which grows relatively quickly. It is therefore well-adapted to semi-arid and arid conditions. Its characteristics make it suitable not only for cultivation for oil production, but also for use as a live fence and for reclamation of eroded land. (Kheira 2009)

Under stress, such as low sun radiation, drought and cold weather, Jatropha can retrieve and store the nutrients from its leaves, which then turn yellow and are shed. The stem remains photosynthetically active, and in this state the plant can survive without rain for over a year. (Fact Foundation 2009a) For a longer period of time it survives with an annual rainfall of 250 to 300 mm but at least 600 mm is needed for flowering and fruit yield. The ideal average annual rainfall for seed production is reported to be 1000-1500 mm and the most favourable temperature is 20-28^{o}C. However, the crop has been reported to withstand a light frost. Very high temperatures can affect the yield in a negative way, but it is not preferable to grow Jatropha in shade since it is adapted to high light intensity. (Brittaine 2010)

Regarding preferred soil type, Jatropha is said to be adaptable and can grow almost everywhere except on waterlogged land. It grows on gravelly, sandy, and saline soils and can be found in the poorest stony soil and even in the crevices of rocks. (Kumar 2008) The preferred soil pH is between 6.0 and 8.0/8.5. (Brittaine 2010)

Jatropha is reported to be pest resistant. According to Brittaine and Lutaladio (2010) observations of free-standing older trees confirm this, but for monocultures pests and diseases are frequently reported.

2.3.Cultivation of Jatropha

Depending on region and climatic conditions there are several different methods for cultivation of Jatropha: direct seeding, pre-cultivation of seedlings (nursery raising), transplantation of spontaneous wild plants, and direct planting of cuttings. Plants propagated by cuttings do not generally live as long and have a lower resistance to drought and diseases than plants propagated by seeds. A reason for this is that these plants' taproots may only reach half to two-thirds of the soil depth compared to taproots produced by plants propagated by seeds. (Kumar 2008)

Spacing in plantations varies depending on what the purpose of the plantation is and how it will be managed. A plantation of a rectangular shape, a block plantation, with a plant spacing of 2.5 × 3 meters is commonly used and generates 1333 plants per hectare. With this pattern the plant has the space it needs for growing and branching, and intercropping is possible the first and even the second year during which Jatropha is still growing slowly. Wider spacing enables the plant to grow larger and higher, making pruning and harvesting more difficult. A more narrow spacing, such as 2 × 2 meters (2500 plants per ha) or 2.5 × 2.5 meters (1600 plants per ha), requires more labour due to the more extensive pruning needed in order for the plants not to grow into each other. This spacing also requires soil with good nutrient and water supply due to its intensity. (Fact Foundation 2009b) To optimize the yield for individual plants some recommend using a wider spacing, such as 4 x 2 and 4 x 3 meters, and agroforestry systems with a spacing of 5x2 and 6x6 meters. It has been observed in 2.5 year old plantations that increasing the spacing significantly increases the seed yield per tree but the seed yield per area decreases. (Achten 2008) Estimates of yield vary depending on country and region; according to Kumar (2008) estimates range between 0.1 and 15 t/ha/year.

Other conditions affecting the choice of spacing are intercropping, mechanized agriculture, and whether the plants are to be used as live fencing. For permanent intercropping the spacing between the rows should be sufficient for growing the other crop, most commonly 4 meters, and the spacing between Jatropha plants within a row is usually 2.5 to 3 meters. For mechanized agriculture, the spacing depends on the machines used. For example, if 2 meters is needed for the machine one should leave room for 1 meter of branches on either side, resulting in 4 meters between rows, and the spacing between plants can be less in this case, 1.5 meters. When using Jatropha as live fencing the spacing between plants should be 25 cm and single or double rows can be used. (Fact Foundation 2009b) Jatropha can also be planted in embankments surrounding fields, called bunds, which improves rainwater infiltration (Brittaine 2010).

Jatropha plantations need to be managed. Weeding, pruning, and thinning are activities mentioned in the literature. (Achten 2008) Weeding is especially important before the Jatropha plants mature and shade the ground, competing weeds should be controlled regularly. Pruning during the dry season when the plant is dormant is important, to increase branching and thereby the number of inflorescences on the branch tips. This also creates a lower plant which is easier to harvest. The first pruning should be done after six months and then once a year. After ten years the tree can be cut down to 45-cm stumps, which will improve yields. The tree will grow back quickly and bear fruit again within a year. (Brittaine 2010) Thinning of the plantations is also recommended, reaching a final density of 400-500 trees per hectare when the trees are mature (Achten 2008).

Most information available on Jatropha suggests that it is a low input crop, however, inputs of irrigation and fertilizers are needed in order to maintain a productive crop. When the rains are not sufficient irrigation is needed after planting but can be discontinued after approximately 3 months, when the plants have developed root systems. Further irrigation may enable higher yields but might not be economically viable depending on the market price of Jatropha and the costs of irrigation. (Fact Foundation 2009a) Additionally, if too much water is applied, using for example drip irrigation, there may be an increase in biomass at the expense of seed production (Brittaine 2010). According to Brittaine and Lutaladio (2010), sufficient data on fertilizer response is not available to give specific recommendations but a trial study performed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) showed that fertilization to an optimal level increased yield while applying excess fertilizer had a negative impact on the yield.

The optimal time for planting Jatropha, regardless of use of seeds, seedlings, or stem cuttings, is at the onset of the rainy season. Land preparation usually involves clearing the land and preparation of planting pits. Under optimal conditions Jatropha can flower 3-6 months after being planted, when using seeds. Another 90 days are needed for the fruit to mature. (Fact Foundation 2009b) When the fruit colour has changed from green to yellow-brown it is time to harvest. In wet climates harvesting is done continuously during the year while in the semi-arid regions it may be limited to two months. However, the fruits do not ripen exactly at the same time requiring weekly picking which makes it difficult to mechanize. The fruits are either handpicked or knocked to the ground by beating the branches with sticks. (Brittaine 2010) After harvest the plant either enters a dormant state or flowers again. (Fact Foundation 2009b)

2.4. Jatropha biodiesel

The harvested Jatropha seeds are used for production of Jatropha oil and biodiesel. The first step is to extract the oil in the seeds, which can later be converted into biodiesel.

2.4.1. Mechanical and chemical oil extraction

There are two different options for extracting oil from the Jatropha seeds: mechanical extraction and chemical extraction. In both cases the seeds have to be dried prior to extraction, either in an oven or in the sun. (Achten 2008)

Mechanical cold pressing of seeds is the conventional extraction method, due to its simplicity and affordable investment cost already at small scale (Aadrians 2006). For mechanical extraction either an engine-driven press or a manual press can be used, where the engine-driven option is reported to extract a higher percentage of the available oil, normally 75-80 percent compared to 60-65 percent for the manual press. The mechanical expeller can be fed with either whole seeds, kernels or a mix of the two (Achten 2008).

Chemical extraction methods were developed in order to achieve a more complete extraction, where the amount of oil per ton of seed increased. The chemical extraction methods use a solvent. The most common solvent used in extraction of Jatropha oil n-hexane, which extracts 95-99 percent of the oil. However, the use of solvent-based oil extraction is only economical at large-scale production. Also, the use of n-hexane as a solvent generates large amounts of waste water, requires high energy consumption and causes emissions of volatile organic compounds, and affects human health by forcing operators to work with hazardous and flammable chemicals. (Aadrians 2006) New production units for extraction with n-hexane as a solvent are more efficient and have a lower environmental impact, but research and development of alternatives, such as supercritical or bio-renewable solvents, could be useful. Environmental impacts can also be decreased by substitution of solvent based oil extraction with aqueous enzymatic oil extraction, but that would lead to decreases in the percentages of oil extracted. (Achten 2008)

2.4.2. Conversion to biodiesel

The Jatropha oil can be used directly as a liquid fuel in older diesel motors, in generators and pumps running at a constant speed, or in newer engines with small modifications in the fuel system. The Jatropha oil can also be mixed with fossil diesel before use in the engine, which combines the properties of the fossil fuel with the lower environmental impact of the vegetable oil. (Siddharth 2009, Achten 2008) However, Jatropha oil has a viscosity that is 20-25 times higher than the viscosity of conventional diesel, which causes problems when using the unmodified oil or blends with a high percentage of Jatropha oil in an engine. Thus, there is a need for modification of the oil to reduce viscosity and make it more suitable as an engine fuel. (Siddharth 2009) Methods for this are pyrolysis and micro-emulsification with solvents like methanol, ethanol, and butanol, but the most common method is to convert the Jatropha oil into biodiesel through transesterification. This method transforms an ester into another ester; in this case a reaction between Jatropha oil and methanol is used to produce a methyl-ester (biodiesel) with glycerol as a by-product. The biodiesel can be used directly in a diesel engine or in a blend with conventional diesel. (Siddharth 2009, Achten 2008)

2.4.3. By-products

There are three important by-products from the production of biodiesel from Jatropha: the seed husk from the seed production, the seed cake produced in the oil extraction, and the glycerol from the transesterification.

The seed husks that are removed before oil extraction can be used directly for combustion, but also as feedstock for gasification. Fuel characteristics are reported to be comparable to those of wood (Achten 2008, Vyas 2006).

Remaining from the oil extraction from seeds and kernels is a seed cake, with an oil content that depends on the efficiency of the extraction method. The seed cake contains high quality proteins (Achten 2008) but also various toxins which make it unsuitable as a fodder (GEXSI 2008). However, if detoxification methods become feasible, the use of the seed cake as animal feed becomes beneficial (Achten 2008). Studies show that the seed cake is rich in plant nutrients which make it valuable as an organic fertilizer (Planning Commission 2003). The toxins make it work as a biopesticide (Achten 2008). Jatropha farmers commonly bring back seed cakes to the fields for fertilizing purposes (GEXSI 2008). But still there are few studies on long-term impact of the toxins on soil and crops, and more research is needed, especially if the cake is to be used as a fertilizer for food crops. It is also possible to combine the use of seed cake as a fertilizer with production of biogas, through anaerobic digestion of the cake before using it on agricultural soils. (Achten 2008)

Glycerol is produced in the transesterification of Jatropha oil into biodiesel. The glycerol can be used to produce heat by combustion, but it can also be used in the cosmetic industry as a feedstock for production of soaps and other products. (Achten 2008)

2.5. Environmental impact

The environmental impact of the Jatropha biodiesel production has been evaluated by several studies applying the Life Cycle Assessment approach. This approach shows the total environmental impact for the production system during its whole life cycle. It determines the processes in the system that contribute most to environmental impact and where the possibilities for improvement are. These assessments show varying results, possibly due to differences in methodology.

2.5.1. Energy balance

If the energy output of a given system is greater than the energy input, the system has a positive energy balance. However, energy balance is affected by energy quality and the utility of different energy carriers. A high energy input can be acceptable if the input energy is low-quality and the output a high-quality energy carrier, such as a liquid fuel usable for vehicle operation. The production of Jatropha biodiesel reportedly has a positive energy balance (Achten 2007). The largest differences in energy requirement between different production sites are derived from differences in cultivation intensity, as irrigation and use of fertilizers are energy intensive practices (Achten 2007). Higher cultivation intensity does not always pay off in higher energy production, and optimization of inputs and yield is required for maximized positive energy balance. Another energy intensive production step is the transesterification of Jatropha oil into biodiesel, which implies that the direct use of crude Jatropha oil would improve the energy balance. However, in the use phase, the combustion of

Jatropha oil instead of biodiesel is less energy efficient and causes problems to the engine. Hence, possibilities for improvement of energy balance lie in the cultivation and transesterification steps. (Achten 2008)

2.5.2. Global warming potential

Studies report that production of Jatropha biodiesel releases less greenhouse gas (GHG) emissions compared to production of fossil diesel (Prueksakorn 2006). The largest GHG contributing phases of the production are use of fertilizers and irrigation, if applied in the cultivation process, and transesterification. Hence, intensification of cultivation will have a negative effect on the global warming potential of Jatropha biodisel production. However, Prueksakorn and Gheewala (2006) find the end-use phase of the biodiesel to be the main contributor of GHG emissions, responsible for 90 percent of total life cycle emissions (Prueksakorn 2006), and therefore changes in production processes would only affect total emissions marginally. Further, Prueksakorn and Gheewala mention that GHG emissions from production and use of biodiesel are 23 percent of emissions from fossil diesel. The main reason for this is that biodiesel is produced from biomass, and its carbon dioxide (CO_2) emissions from combustion in the engine are considered GHG neutral. (Prueksakorn 2006) Biodiesel in general releases less emissions than fossil diesel, except for emissions of nitrogen oxides (NO_x), where emissions are slightly higher (Siddharth 2009). Nitrous oxide (N_2O) emissions from the use of nitrogen fertilizers also need to be considered; IPCC estimates the emissions to be one percent of nitrogen input from fertilizers. (IPCC 2006) As nitrous oxide is a potent GHG, with a global warming potential that is 296 times higher than that of carbon dioxide, it is important to optimize the input of fertilizer to the output from cultivation to reach a reduction in global warming potential for the system. (Achten 2008)

Destruction of carbon stocks by removal of natural and semi-natural forest for plantation of Jatropha will have significant negative effects on the life cycle global warming potential, and pay-back of stocks through reduction of GHG emissions by the use of biodiesel will take a long time. (Achten 2008)

Jatropha may contribute to GHG savings by carbon fixation in the biomass, as only the seeds are harvested while the biomass may remain standing for a long period of time. Studies report carbon uptake by mature Jatropha plants ranging from 25 tC/ha on rainfed Indian wasteland to 40 tC/ha on irrigated land in Egypt. (Romijn 2009) An IFEU (Institute for Energy and Environmental Research) report estimates the carbon content of a 3.5 year old plantation on infertile Indian soil to 5 tC/ha (Reinhardt 2007). Although spacing patterns vary, the number of plants per hectare is not likely to have significant influence on carbon uptake, since denser plantations demands increased extent of pruning which results in decreased biomass per plant (Romijn 2009).

2.5.3. Land use changes

The impact of Jatropha cultivation on land use changes will be influenced by several factors, the most important being the original use of the land, the used cultivation system, and cultivation intensity (Achten 2008). Expected positive impacts on soil include improvement on soil structure, prevention of soil erosion, and carbon sequestration. Intensification of cultivation methods is a driver toward negative impact on soil. (Achten 2007) The impact on biodiversity depends on what land use is replaced by Jatropha plantations and the methods for cultivating Jatropha (Achten 2008). Cultivation on barren and unused wasteland can help restore local biodiversity (Achten 2008), while replacement of natural or semi-natural vegetation will have negative effects on biodiversity, especially if Jatropha is grown as a monoculture (Achten 2007). No significant effect on biodiversity is expected if Jatropha is cultivated in intercrop or agroforestry systems, or planted for fencing. As Jatropha is a non-native crop in India, and relatively recently imported, its invasiveness and impact on native species in the local area are still uncertain (Achten 2008).

2.5.4. Water related impacts

Water scarcity is a problem in large parts of India, and climate change and intensification of agriculture further increase stress on the scarce water resources. A growing demand for bioenergy creates increased requirements for water for irrigation of biofuel crops, and conflicts between water use for energy and use for other agricultural production are becoming an issue.

One of Jatropha’s main mentioned advantages is its resistance to drought and its low water requirements. The ability to grow Jatropha under dry conditions and increase the vegetation cover on degraded land gives opportunities for channelling of water, which earlier evaporated from the ground, into positive transpiration. However, a possible negative impact from this is that the increased evapotranspiration from the plantations causes decreased water supply downstream.

The use of irrigation for Jatropha plantations puts stress on the limited resources in water-scarce areas; efficient water management is necessary for optimal use of the scarce resources. Calculations of the total water footprint of Jatropha exist, but they vary widely. According to Gerbens-Leenes (2009) the water use for Jatropha biodiesel in India is very inefficient, and the production of one GJ of energy requires 600 m^3 of water, which equals 20,000 litres of water per litre of biodiesel. For comparison, the water footprint for sugar cane for production of ethanol is 110 m^3/GJ. (Gerbens-Leenes 2009) This high water footprint value is criticized by Maes (2009) who claim the value is an overestimate caused by methodological errors and inappropriate use of data. Maes (2009) estimate the water footprint at 65 m^3/GJ, only 16 percent of the value calculated by Gerbens-Leenes (2009). To use water resources more efficiently, the amount of water for irrigation should be optimized relative to outcome, and waste water from industrial processes, such as oil extraction and transesterification, should be reduced.

Possible impacts of emissions to water, from for example use of fertilizers and combustion of fossil fuels, include negative effects on household water and acidification and eutrophication of water flows (Reinhardt 2007).

3. The Indian context

India depends on imports of crude oil to satisfy energy demands. As the population and economy continue to grow, the demand will continue to increase. Concurrently, the pressure to reduce environmental impact and mitigate climate change mounts. The hope is that domestic production of biofuels will replace some of the fossil fuel use to reduce dependence on imported oil and address environmental issues. (Planning Commission 2003)

Production of biofuels can contribute to socio-economic development through secured energy supply and employment opportunities. However, it is also important to develop and enhance the agricultural system to ensure the supply of food and agricultural products. Cultivation of energy crops can conflict with agricultural activities for food production. To avoid the energy versus food conflict, it is important to take the existing agricultural system into regard and develop an energy production system that does not compete for the same resources. (Planning Commission 2002, Kadia 2008)

3.1. Biofuel initiatives

In 2003 the Indian government declared a National Mission on Biofuels, to drive large-scale implementation of biofuel production. (Biswas 2009) In 2008 the national mission was replaced by a new biofuel policy. However, when studying Jatropha biodiesel production it is important to consider the first national mission, since it determined the prevailing conditions during the large-scale implementation of the Indian Jatropha programme in 2003-2006.

3.1.1. National Mission on Biofuels

The National Mission on Biofuels stated a five percent blending target of biodiesel in conventional diesel, with a 20-percent blending target for 2012. (Biswas 2009) The mission also announced an expansion of the existing ethanol production to reach the same target. The programme aimed to contribute to energy security, especially in rural areas, and to reduce dependence on imports of crude oil. By introducing a fuel superior to conventional diesel from an environmental point of view, the programme sought to reduce environmental impact, address global pressure for reduction of carbon emissions and mitigation of climate change, and follow enhanced automotive vehicle standards. Cultivation of biofuel crops would also provide soil nutrients, reduce soil erosion and land degradation, and help rehabilitate degraded lands through greening. For socio-economic development, the programme sought to provide a more widespread energy supply and to create employment in rural areas. (Planning Commission 2003)

As the demand for edible oil in India is higher than the domestic production of the product, production of biodiesel from edible oil would cause competition with food production. Hence, there was a need for evaluation of crops suitable for production of non-edible oil. Studies found (Planning Commission 2003) that Jatropha and *Pongamia Pinnata* were among the most promising for the prevailing conditions. The Planning Commission for the National Mission on Biofuels announced that Jatropha was found most suitable for the stated energy, environmental, and socio-economic purpose.

The following list, adopted from the Planning Commission's report, shows the reasons Jatropha was found most suitable (Planning Commission 2003):

- Oil yield per area is among the highest of tree borne oil seeds.
- It can be grown in areas of low rainfall (200 mm per year) and in poor soils. In high-rainfall and irrigated areas it can be grown with much higher yields. Therefore, it can be grown in most parts of the country.
- Jatropha is easy to establish, grows relatively quickly, and is hardy.
- Jatropha lends itself to plantation with advantage on lands developed on watershed basis and on low-fertility marginal, degraded, fallow, waste and other lands such as along canals, roads, railway tracks, on borders of farmers' fields as a boundary fence or live hedge in arid/semi-arid areas, and even on alkaline soils. As such it can be used to reclaim waste lands in forests and outside.
- Jatropha seeds are easy to collect as they are ready to be plucked before the rainy season and as the plants are not very tall.
- Jatropha is not browsed by animals.
- Being rich in nitrogen, the seed cake is an excellent source of plant nutrients.
- Seed production ranges from about 0.4-12 t/ha.

To produce a sufficient amount of biodiesel to achieve the 20 percent blending target, the Planning Commission for the national mission calculated that 13.4 million tonnes of biodiesel was needed, which would require 11.2 MHa of land for cultivation of Jatropha (see Table 1). Required land area is calculated based on plantation density of 2,500 plants per hectare and seed production of 1.5 kg per tree.

Table 1. Biodiesel demand and land requirements for 5 and 20 percent blending calculated by the Planning Commission.

Year	Diesel demand (MT)	Biodiesel demand (MT)		Area needed (MHa)	
		5% blending	20% blending	5% blending	20% blending
2003-04	44.51	2.23	8.90	1.87	7.48
2004-05	46.97	2.35	9.39	1.96	7.84
2005-06	49.56	2.48	9.91	2.07	8.28
2006-07	52.33	2.62	10.47	2.19	8.76
2011-12	66.90	3.35	13.38	2.79	11.19

Source: Planning Commission (2003)

The Planning Commission identified and estimated land areas available, concluding that 13.4 MHa of land was available and feasible for immediate plantation. An additional 4 MHa of wastelands could also be planted (see table 2).

Table 2. The Planning Commission's estimate of available land areas for Jatropha plantations

Type of land	Area (MHa)	Potential area for Jatropha (MHa)
Under-stocked forest areas	31.0	3.0
Protective hedge around agricultural fields	142.0	3.0
Agro-forestry		2.0
Cultivable fallow land	24.0	2.4
Wastelands under Ministry of Rural Development poverty alleviation programmes		2.0
Public land along railways, roads, and canals		1.0
Total		**13.4**
Additional wasteland		4.0

Source: Planning Commission (2003)

The Planning Commission acknowledged the need for demonstration of the viability of the programme before large-scale implementation and involvement of a large number of stakeholders, including private farmers, communities, industry, financial institutions and government institutions. Therefore, the National Mission on Biodiesel was proposed in two phases. Phase 1, from 2003 to 2007, consisted of a demonstration project. The objectives of this demonstration project were (Planning Commission 2003):

- Lay a foundation for a self-sustaining and fast-growing stakeholder-driven biodiesel production programme
- Produce a sufficient amount of Jatropha seeds
- Test, develop, and demonstrate the viability of all components of the programme, and estimate its cost and benefits
- Widely inform and educate all potential participants of the programme

The Planning Commission estimated that the demonstration project would generate 127.6 million person days of plantation work and 36.8 million person days in seed collection. On a sustained basis the employment generation would be 16 million person days per year. (Planning Commission 2003)

The experiences from the Phase 1 demonstration project would provide the foundation for the second phase, where a self-sustaining expansion of the programme would lead to production of the biodiesel required to achieve the 20 percent blending target in 2012. The first demonstration phase of the mission was driven by the government through national and state government agencies and under already existing poverty alleviation programmes. As there was no awareness of short-term economic returns from Jatropha plantations, the funds could not be expected to come from the private actors; the mission stated that plantation investments had to be done by the government. The second phase would rest more on initiatives from private farmers, communities, NGOs and industry with support from financial institutions. Here the government would act mainly as a facilitator for policy support and support in critical areas identified during the demonstration project. Experiences from the demonstration project were supposed to attract farmers to spend their own money, with support from subsidies and bank loans. (Planning Commission 2003)

Sometime during the first phase of the National Mission on Biofuels, it became clear that the project was not successful; the production of biodiesel from Jatropha, initiated during the national mission, was not living up to the high expectations. The mission was heavily criticized as it failed to address important issues and because many parts were not implemented correctly. (Donizeth 2008, Shailesh 2009) This study reports on some of the problems encountered during the demonstration phase. As a consequence of the failure, in 2008 the National Mission on Biofuels was aborted. A new policy, the National Biofuel Policy, was introduced.

3.1.2. National Biofuel Policy

The National Biofuel Policy sets a 20 percent blending target of biodiesel to conventional diesel, to be achieved by 2017. Like the former national mission, the new policy aims to reduce environmental impact and contribute to energy security and rural development. It further emphasizes some of the issues that were criticized in the national mission. For example, the policy focuses more on avoidance of conflict between energy and food security. It is clearly stated that biofuels should be based on non-food feedstock raised on land that is not suitable for agriculture. Plantations are to be created on government or community land classified as degraded, fallow, or wasteland in forest and non-forest areas. Private plantations and corporate contract farming can be established through a Minimum Support Price mechanism proposed in the policy. (Ministry of New & Renewable Energy 2008)

An important difference between the former National Mission on Biofuels and the new biofuel policy is that while the national mission stated that Jatropha would be used as feedstock for the required biodiesel production, the new policy does not put forward any certain crop as more suitable than others. Instead the potential and techno-economic viability for production of biodiesel of more than 400 indigenous species of trees bearing non-edible oilseeds will be exploited. The policy will support continuous research, development, and demonstration on all aspects of biofuel production, from feedstock production to end-use applications. Support will also be given to development of new and second generation biofuel feedstocks and more efficient conversion technologies. (Ministry of New & Renewable Energy 2008)

3.2. The agricultural system in India

The development of large-scale biodiesel production impacts, and is affected by, the existing agricultural system. It is therefore essential to understand the importance the agricultural sector has to the rural population. India's agricultural system can be considered the country's largest private enterprise, with more than a 100 million farm holdings. The agricultural sector contributes to 25 percent of India's national GDP, sustains the livelihoods of two-thirds of the Indian population, and provides direct employment to about 234 million people. (ICAR 2008) The most-produced crops are wheat, rice and different forms of vegetables (IARI 2010). The Indian agricultural sector has developed during the past decades, from need for food imports of 8-10 million tonnes annually in the 1960s to food self-sufficiency, buffer stocks, and food export in the 1990s. This development has been achieved by increasing the area under cultivation (Embassy of India 2008) and through gains in agricultural productivity. (ICAR 2008)

3.2.1. National Agricultural Policy

Increased agricultural productivity has contributed to reducing poverty. However, 250 million Indians still live below the poverty line and depend on continued agricultural development to raise their standard of living. (IARI 2010) In an attempt to face this challenge the Indian government announced the National Agriculture Policy in 2000. The policy seeks to utilize the growth potential of Indian agriculture, support faster agricultural development by enhancing rural infrastructure, create employment in rural areas, secure a fair standard of living for the farmers and agricultural workers and their families, discourage migration to urban areas, and face the challenges arising out of economic liberalization and globalisation. (National Knowledge Commission 2002)

Continued development, economic growth and further population growth put high pressure on natural resources like land, water, and bio-diversity. (IARI 2010) The National Agriculture Policy acknowledges the strains on natural resources by aiming at agriculture growth "that is based on efficient use of resources and [which] conserves our soil, water and bio-diversity". The policy also aims at equal growth, divided across regions and farmers, and growth that is technologically, environmentally and economically sustainable. (National Knowledge Commission 2002)

An integral part of the National Agriculture Policy is the Farm Produce Price Policy that annually announces minimum support prices for the major agricultural commodities. The policy seeks to ensure farmers incomes that encourage increasing investment and production. (Department of Agriculture and Cooperation 2006)

3.2.2. Connection between agriculture and rural livelihoods

Agricultural development is closely connected to rural development as agricultural factors have large impact on rural poverty and hunger. One of these factors is farm size; studies show that 54 percent of the landless population in India live below the poverty line[1], and that even small landholdings can have a great impact, as the number of poor is reduced to 38 percent for the population owning up to 0.5 Ha of land. Ownership of livestock affects the livelihood of rural farmers; the percentage of the population living in hunger, and poverty is lower among those who have a cow or buffalo than among those who have no livestock. In the relation between poverty and agricultural practices, the use of irrigation is an important factor, and the concentration of poor are larger on rainfed lands than in irrigated areas. Apart from agricultural factors, literacy rate seems to have an impact on the livelihood in rural India; a larger part of the illiterate population live below the poverty line. The literacy rate has an important role in development of agricultural productivity and practices, and will become even more important with globalisation and further modernisation of the agricultural system. (IARI 2010) See Appendix I for tables.

3.2.3. Development of rainfed farming and rural liveliohoods

One of the toughest challenges is for Indian agriculture to enhance conditions for rural farmers by transforming rainfed farming into more sustainable and productive agricultural systems. A large part of India's poor rural farmers live on rainfed lands and are dependent on natural water resources for sustaining their plantations. Rainfed agriculture is characterized by low levels of productivity and low intensity in inputs, and variability in rainfall causes varied and instable yields. As climate change and increased stress on natural resources cause changes in agricultural conditions, the conditions for farmers on rainfed land become even tougher. (ICAR 2008) Facing the challenge of developing rainfed farming, the national government established the National Rainfed Area Authority (NRAA), to increase focus on the problems of rainfed areas (The National Portal of India 2010a).

[1] The government of India has estimated the national poverty line to Rs. 356.30 per capita per month (Planning Commission 2007)

Several government programmes aim at development of rainfed agriculture and enhancement of livelihoods for the rural poor. Among these are the Comprehensive Land Development Programme (CLDP), the Drought Prone Area Development Programme (DPAP) and the Integrated Wasteland Development Programme (IWDP).

For a sustainable development of rainfed farming, the Indian government has put high priority on implementation of the watershed approach, aiming at conservation and management of water. A watershed is defined as a geographic area that drains water to a common point, and can include one or several villages, arable and non-arable land, and various categories of farmers and land-holdings. The focus in water resource management is not only on creation of new water resources but also on more efficient utilization of existing resources, for example by adoption of efficient irrigation systems and substitution of high water requiring crops by low water requiring crops. Studies on impacts of watershed projects have shown increase in groundwater recharge, increased water resources, enhanced cropping intensity, higher yields, and reduced loss of soil nutrients. (ICAR 2008)

3.3. Jatropha in India

Jatropha may be more suitable than other crops for production of biodiesel, because of its stated properties. India is one of the leading countries in Jatropha plantations and expectations on the production of biodiesel from the crop have been high, not least because of the National Mission on Biofuels and the National Policy on Biofuels. However, Jatropha projects have not been as successful as expected, mostly due to difficulties in reaching satisfying yields. As Jatropha is a relatively new agricultural crop, it is hard to find reliable statistics on its performance.

3.3.1. Potential yields in India

Jatropha is put forward as a highly adaptable crop that can be cultivated in a wide range of ecological conditions. However, studies show that crop performance depends on the agricultural environment, which is why the potential yield differs widely among cultivation sites in different parts of India. Also, potential yield depends on cultivation techniques, with the main contributing maintenance factor seeming to be whether the crop is rainfed or irrigated. For the rainfed case, reports show (Lapola 2009) that most of the country could reach a potential seed yield of 1-3 t/ha, with somewhat smaller yields towards the Northeast. The most productive areas in India are the Eastern states and small parts of the Southern states of Tamil Nadu, Karnataka and Kerala, where potential seed yields are reported to peak at 5.2 t/ha (Lapola 2009). If irrigated, most areas in India can reach a productivity of 5.8 t/ha, and peak yields have been reported to be 6.9 t/ha (Lapola 2009).

3.3.2. Land requirements to reach blending target

According to the report preceding the now shut-down National Mission on Biofuels, an additional 11.2 MHa of Jatropha plantations was required to reach the 20 percent blending target by 2012 (Planning Commission 2003). For the new target stated in the National Policy on Biofuels, to reach 20 percent blending by 2017, an additional 14 MHa is estimated to be required (Thukral 2010). Requirements estimated by Lapola (2009) differ a little; they state that the land requirement is affected by the variation in potential productivity and calculate the required land to range between 9.5 and 41 MHa depending on if the cultivation sites are in high or low productivity areas. Lapola (2009) also mention that land requirements can be further decreased if plantations are irrigated, and that the high productivity number can be as low as 7.9 MHa with the use of irrigation.

Out of India's total land area, 55.25 MHa are classified as wasteland or degraded land and could theoretically be available for plantation of Jatropha (DoLR 2004). See Appendix II for categories and areas of wasteland. However, not all this land is optimal from an agricultural point of view, as the classification includes for example areas of bare rock and glaciers. A large part of the area is land along roads and railways, which can result in widely spread plantations and demand for longer transports. Also, large parts of the land are not sufficient to produce satisfying yields, but here Jatropha cultivation might still have positive effects in hindering soil erosion and improve land fertility. As a part of the National Mission on Biofuels, the Planning Commission identified and estimated the wasteland and other land available for Jatropha cultivation, and agreed on 13.4 MHa of land being available and feasible for immediate plantation of Jatropha. Thus, this was sufficient to reach the 20 percent blending target according to their own estimation of the required land.

3.3.3. Controversy

Doubtful environmental impacts and the failures in reaching satisfying yields have brought criticism to the Jatropha programme. But what seems to cause more controversy, especially at the local level, is the appropriation of the land used for Jatropha plantations.

As mentioned earlier, a base for the whole Jatropha programme is the classification of wastelands, which determines the land available for plantations. These wastelands include large areas within forests, like degraded and under-stocked forest, and arid and semi-arid ecosystems. In the search for available wastelands, attention has been drawn to resources referred to as Common Property Resources (CPRs). CPRs include all natural resources where no individual has exclusive property rights, but that are collectively held and used by the inhabitants of a community. This includes grazing lands, different types of forest land, and several types of water resources.

Historically, CPRs constituted a large part of India's natural resources; these were controlled by local communities and available for the rural population's use. However, as state control over natural resources increased, the CPRs available for the population decreased, and today communities have limited rights to land and water resources. Nevertheless, CPRs are still important for the sustenance and livelihood of India's rural communities. (National Sample Survey Organisation 1998) Through the Indian government's classification of wasteland and identification of land suitable for Jatropha plantation, CPRs risk becoming even less available.

Also of great importance, especially to the poor and landless population, is land that is not private property but owned by government departments. This includes land categories such as barren land, land under non-agricultural uses, and degraded forests, which are classified as wasteland. (National Sample Survey Organisation 1998) These areas are often inhabited and used by communities of indigenous and landless people, who do not consider the land to be wasteland. They rely on the land for food and energy and for grazing of animals. In many cases the plantation of Jatropha on wastelands has involved forceful methods of driving these communities from the lands they have inhabited for generations. (World Rainforest Movement 2009, Lahiri 2008)

4. Research Methodology

This chapter presents the applied research process and strategy along with the method for data collection, description of the data, sampling method, and method for interpretation of results. The validity and reliability of the results generated by the strategies and methods used are discussed as are ethical considerations.

4.1. Research process and strategy

Different strategies and approaches can be employed in structuring a research project. This study has used an iterative process illustrated by the figure below, Figure 4.

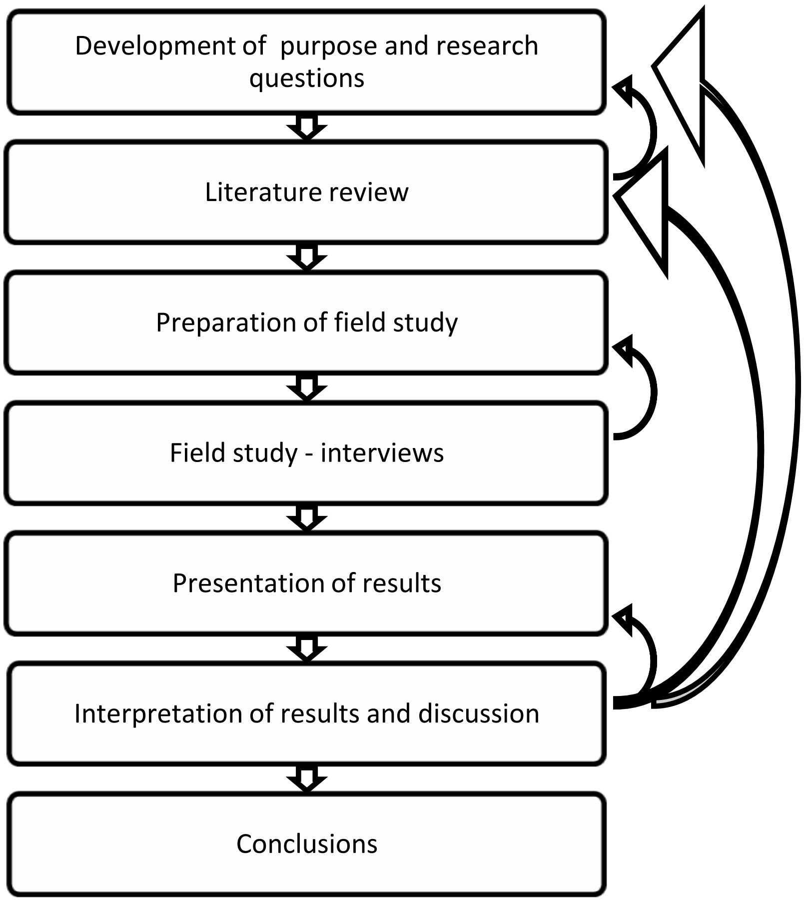

Figure 4. Iterative project process

This process was chosen deliberately to enable flexibility when encountering new information and to generate as consistent a report as possible. The purpose and research questions were reformulated during the study and the literature review was modified in light of findings from the field study and interpretation of these findings.

Quantitative and qualitative research strategies can be distinguished by how the data are collected and analysed, see Table 3 (Saunders 2000).

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Table 3. Distinctions between quantitative and qualitative data

Quantitative data	Qualitative data
Based on meanings derived from numbers	Based on meanings expressed through words
Collection results in numerical and standardized data	Collection results in non-standardized data requiring classification into categories
Analysis conducted through the use of diagrams and statistics	Analysis conducted through the use of conceptualisation

Source: Saunders *et al*., 2000, p. 381.

This study combines the two strategies and collected both quantitative and qualitative data. The quantitative data were collected in the form of measurements of the existing plantations, as numerical and standardized data through the interviews, and in government records provided by local authorities. Qualitative data were collected through interviews with farmers and informal discussions with government officials and other concerned actors.

A research project can aim at being exploratory, descriptive, and/or explanatory (Saunders 2000). This study intends to be both descriptive and explanatory as it gives a description of the current and historical situation of Jatropha and attempts to clarify why the situation is what it is.

4.2. Data collection methods and description of the data

There are two main categories of data, primary and secondary data. Primary data are new data collected in order to answer the research questions of the specific study, and secondary data are already existing data (Saunders 2000). Primary data for this study were collected during the field study in Southern India, through interviews, and measurements of Jatropha plantations.

4.2.1. Primary data - Interviews

The interviews performed during this study can be regarded as having a mixed structure, both structured and semi-structured. The main purpose was to assess whether the respondents were still growing Jatropha and the reasons for continuation or discontinuation.

4.2.1.1. Interviews

Due to the characteristics of the respondents, interviews in person were chosen as the data collection method over surveys or telephone interviews. To travel to the rural areas asking the local population for directions was the best option for meeting the respondents, as the farmers' and their villages' exact location was not known in all cases; few had exact addresses and even fewer had known telephone numbers. The respondents' literacy was often limited, and handling the language differences is easier in person than over the phone. Conducting an interview, as opposed to conducting a survey, also enables the interviewer to assist when a respondent has difficulties answering a question and to intervene when it is of interest that the respondent elaborates an answer (Bryman 2007). Additionally, when conducting an interview in person the interviewer also has the chance to observe the location, which was useful during this project in conjunction with validating the answers.

Issues that need to be addressed when conducting interviews include interviewer effects and interviewer variability (Bryman 2007). The fact that the interviews were performed in a country with a different culture and a language different from the languages spoken by the interviewers added to the effects and variability usually considered. A major effort was put into learning about the culture, adopting manners and clothing style, hopefully reducing the possible negative effects from showing disrespect due to ignorance. A translator was present during the interviews to manage the language differences, adding to the interviewer effects and variability. These issues are discussed further in *4.4 Reliability* and *4.5 Validity*.

The interviews performed can be regarded as having a mixed structure, structured and semi-structured. In structured interviews the respondents are asked the exact same questions to facilitate aggregation and comparison of the results in a reliable way. A semi-structured interview uses an interview guide which specifies what information is to be gathered. The respondents are allowed to openly answer the questions, though the researcher knows what information is important. (Bryman 2007) The interview guide used within this study has structured sections, with questions asked in the exact same way or questions generating a very specific answer, quantitative data such as number of hectares, thus enabling aggregation and comparison. It also includes questions of an open nature where the respondent was allowed to answer freely resulting in different answers from all respondents.

4.2.1.2. Developing the interview guide

Since this study followed up an earlier study, the previous study's interview guide was used as a template when constructing the new guide to facilitate comparison of results. Additional questions were included to enable addressing the purpose of this study.

The interview guide is divided into different parts: Socio-economic conditions, Jatropha plantation details, Inputs into Jatropha plantations, Returns or Outputs from Jatropha Plantations, Marketing details and Concluding questions (See Appendix III for the complete interview guide).

The questions included in the previous study had been thoroughly tested in the field, but together with the additional questions for this study they were also critically reviewed by persons with relevant knowledge, resulting in removal and rephrasing of questions. Later the interview guide was gone through thoroughly with the translators to ensure they understood the questions and what the purpose of each question was, to facilitate correct translation.

After the first couple of interviews, additional rephrasing was done of a few questions, in order to facilitate the interview procedure.

4.2.1.3. Interview procedure

Depending on how talkative the respondent was the interview took approximately 30 minutes. In the cases where the respondent spoke English, the interviews took less time since the translation step could be skipped.

Two persons plus the translator were always present at the interviews, one person in charge of asking the questions and one recording the answers onto the interview guide. The translation step allowed for the person asking the questions to check the answers the other person present wrote down to make sure the answer was understood in the same way by both persons.

4.2.2. Primary data - Plantation measurements

The environmental benefits achieved from Jatropha plantations include the possibility for the collective biomass of the crops to work as a carbon sink. Through measurements of selected plots the total biomass of the Jatropha plantation was calculated.

Five squares measuring 10 × 10 meters were chosen within the field. The squares selected should together give a representative view of the condition of the plantation. Measurements of girth at breast height (GBH) were made on three branches of each plant higher than breast height. According to prevailing national standards, breast height is chosen as 1.3 meters (Australian National University 1999). The three branches should together give a representative view of the GBH of all branches of the plant. For plants with three or less than three branches, all branches were measured. Plants lower than 1.3 meters were not measured, and were assumed not to contribute to total biomass. Additionally, height of the plant was measured and the total number of branches counted.

For Jatropha plantations in bunds, all plants higher than breast height were measured. Measurements were done in the same way as for plants in block plantations.

4.2.3. Primary data – other

Additional primary data were collected through informal discussions with government officials in both states visited. This information, together with information gathered during the iterative literature review, provided an overview of the Jatropha implementation process and the structure of the Indian agricultural system.

4.2.4. Secondary data

Secondary data were first collected through an exploratory review of the existing literature, using the internet and scientific databases. This was performed in order to get an overview of the availability of information, to gain knowledge, and to establish the theoretical background, incorporated in the report in the chapters *2. Jatropha production system* and *3. The Indian context*. Information on the Jatropha production system has been collected mainly from scientific articles and information on the Indian context was gathered from government webpages and the World Bank. The database most frequently used during the whole project was Science Direct, where keywords such as *Jatropha*, *India*, *energy* and *biodiesel* were used.

Other secondary data used include the data from the previous study performed in 2005, where the respondents included in the sample of this study were interviewed and their plantations measured, as well as official documents from government officials in India. The official documents were not always easy to get hold of even though they should be publicly available. Records were seldom available in digital form. Acquisition required hands-on help with access to government archives; this was not always easy to obtain in the advanced institutional structure.

4.2.5. Sampling method

Sampling techniques can be divided into two categories, probability (representative) and non-probability (judgmental) sampling. Probability sampling means that the sample has been selected randomly so that each individual within the population has an equal chance of being selected. When using non-probability sampling, the sample is not randomly selected meaning that some individuals within a population are more likely to be selected than others. (Bryman 2007)

This study employed a non-probability sampling method, since it was a follow-up study. The sample of farmers to be interviewed was given in the documentation of the previous study. All farmers who participated in the previous study were therefore targeted and additional farmers were added to the sample during the process in order to give a more complete picture of Jatropha cultivation in the different locations. These additional farmers were either encountered at the visited locations, indicated by government officials, or chosen from a list of farmers who adopted Jatropha in 2004-05 based on location and availability.

4.2.6. Ethical consideration

Sociological research is important and necessary both for the development of societies and individuals, but the individuals should not be exposed to inappropriate observation, physical or psychological harm, humiliation, or other violations of rights. According to the Swedish Research Council the basic rights of individuals in relation to research can be summarized in four general requirements on research: information, consent, confidentiality, and usage. (Vetenskapsrådet 2002) These requirements have been taken into account when performing the field study by informing concerned persons, mainly interview participants, of the purpose of the study and of the anonymity of their answers. The interview subjects could then choose to consent to being part of the study.

4.3. Method for interpreting the results

The primary data collected through interviews and measurements of plantations were interpreted in order to provide answers to the research questions. Some data required more than aggregation and comparison to be informative; what follows is a description of the method used for preparing this interview data for interpretation and how the measurements have been used.

4.3.1. Motivational factors, drivers, and barriers

In order to assess what motivational factors were present when a farmer decided to start cultivation of Jatropha and to assess what drivers and barriers to continuation of cultivation exist, the farmers were asked open-ended questions resulting in as many answers as there were respondents. To interpret these data a categorisation of the different answers was made to enable aggregation and identification of the most significant motivational factors, drivers, and barriers.

4.3.2. Calculations of biomass and carbon stock

The measurements taken, described in *1.3.2. Primary data – Plantation measurements*, are further used to calculate biomass and carbon stock as described below.

The measurements of GBH are used to calculate the total basal area of the plant:

$$Basal\ area = \frac{Mean\ GBH^2}{4\pi} * Number\ of\ branches,$$

where *Mean GBH* is the mean value of the measured branches and *Number of branches* is the total number of branches of the plant.

By multiplying the total basal area of the plant with the measured height, the total volume of the plant was calculated. USDA's Forest Products Laboratory has measured four samples of Jatropha wood and their density is 0.33, 0.35, 0.37 and 0.22 g/cm^3 (Benge 2006). A mean value of these densities (0.32) was used for calculation of total biomass. It was assumed that the moist content of the biomass is 15 percent and that 50 percent of the dry biomass was constituted by carbon. The calculated values for the plots were expanded to show values for one hectare. For bund plantations total biomass and carbon content were calculated for all measured plants. For calculation of the annual sequestration rate, the C uptake is divided by the age of the plant. As the growth rate was unknown, it was assumed to be linear, meaning that the biomass fixes the same amount of carbon each year of growth.

4.4.Reliability

Reliability concerns the repeatability of the results of a method or procedure. The same results should be obtained when measuring the same phenomenon under the same conditions but with different procedures or on different occasions. The results should be consistent.

Numerous issues have arisen in connection with the interviews which can be compromising for the reliability of the results; these were managed to the extent possible.

According to Sanders (2000) there are four general threats to reliability:

Participant error: A respondent might unintentionally give questionable answers due to that the questions have not been understood correctly or that the respondent does not feel comfortable at the time or location of the interview. The respondents were interviewed in their home environment and to facilitate their comprehension of the questions the interview guide was thoroughly gone through with the translators and rephrasing was done when necessary.

Participant bias: The respondent could also intentionally alter information for different reasons, giving what is thought to be the “right” answer, saying what he/she thinks the interviewers or other persons present want to hear etc. The respondents participating in this study were informed of the purpose of the study and that their answers would be anonymous. The translators present during the interviews had no relation to the farmers, the Jatropha programme or the government, in order to avoid biased answers.

Observer error: This threat is probably the greatest threat to this study mainly due to the language difficulties which introduces an extra step (namely, translation) into the interview procedure where information can be lost and distorted. To reduce this threat the interview material was thoroughly gone through with the translators prior to the interviews in order for them to understand the purpose of each question and thereby translate it correctly into the local language. Observation, asking similar but rephrased questions and asking additional questions also helped.

Observer bias: This concerns the interpretation of answers and data made by the interviewers based on their background and knowledge. The focus during the interviews and interpretation of the results has been on being objective.

The repeatability of the measurements of the plantations is high since a standardized method has been used.

4.5.Validity

According to Bryman and Bell (2007) validity considers “whether or not a measure of a concept really measures that concept.” Put in another way, validity considers how well the results represent reality and if the results can be generalized beyond the context of the specific study.

Interviews are a threat to validity due to the errors and biases discussed in the previous chapter 4.5 Reliability. It is important to have enough respondents to give a holistic view of the issue in focus. During this study a sample of 106 respondents were interviewed, targeted with the aim to cover farmers having cultivated or cultivating Jatropha within all villages in the areas in focus. By targeting all villages the sample also includes the variety of prevailing conditions in the areas, therefore the authors consider the results representative for the areas in focus.

Regarding the biomass measurements, two assumptions made in the study may lead to errors in the calculations of total biomass and carbon fixation. These possible sources of error are the assumption that the Jatropha stems are cylindrical and the assumption of linear growth of the plants.

5. Description of the field study

The chapter provides a short description of the previous study, and an overview of the studied states and their implementation of the Jatropha programme. Further, it presents an overview of the field study.

5.1. Description of earlier study

The purpose of the study performed in 2005-06 was to gain knowledge on the performance of Jatropha plantations in Southern India and the socio-economic status of the Jatropha farmers. The three studied states, Andhra Pradesh, Tamil Nadu and Chattisgarh, were selected due to their large-scale implementation programmes of Jatropha plantations and the large number of farmers available. Within the states farmers were randomly selected from government records of Jatropha farmers. The goal was to visit farmers in geographically scattered locations to enable comparisons within the state.

A total number of 139 farmers were visited and interviewed, 64 in Andhra Pradesh, 31 in Tamil Nadu and 44 in Chattisgarh. All interviewed farmers had existing plantations of Jatropha planted in 2004-05. Measurements for calculation of biomass and soil samples for analysis of soil conditions were taken at all studied plantations.

After visiting the farmers the data from the field study were compiled, but for unrelated reasons the study was never finalized and no conclusions based on the collected data were drawn.

5.2. Overview of studied states

India is divided into 28 states, which are further divided into different districts and these districts are then divided into blocks, where the district development is administered (The National Portal of India 2010b).

Two of the three states visited in the previous study were visited within this study: Andhra Pradesh and Tamil Nadu.

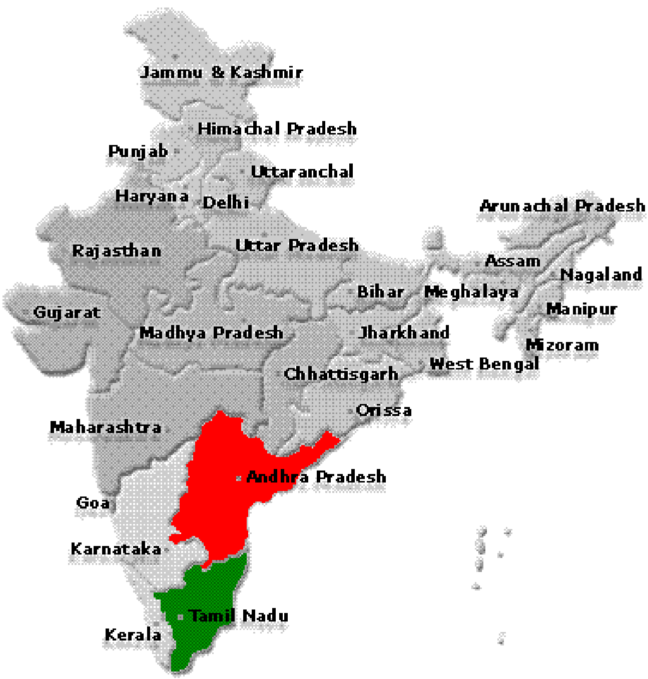


Figure 5. Map of India with the visited states shown in red (Andhra Pradesh) and green (Tamil Nadu).

The state of Chattisgarh was included in the previous study but was excluded in this, mainly due to the fact that none of the actors interviewed during the former study were private farmers, which was the most interesting group, and also due to time limitations. This section gives an overview of the states and districts studied.

5.2.1. Andhra Pradesh

Andhra Pradesh is among the five largest of the 28 states in India, both regarding size and population. It is situated in the south east with an area of 275 069 km^2 and a population amounting to 76 millions. (The National Portal of India 2010c) It is one of India's poorest states with most of the population living in rural areas (The World Bank 2005a).

Agriculture is a major sector in the state, with 62 percent of the population having it as their main occupation. Important crops are rice, sorghum, maize, millets, pulses, castor, tobacco, cotton, and sugarcane, rice being the most important, accounting for 77 percent of the total food grain production. (The National Portal of India 2010c)

The agricultural production in Andhra Pradesh depends on rainfall, where the main sources are the South-West and the North-East monsoons, active during June to September, and October to December, respectively. The South-West monsoon contributes to approximately 66 percent of the total yearly rainfall while the North-East monsoon is responsible for around 24 percent. The normal annual rainfall within the state is 940 mm, but the distribution varies between the districts. (Department of Agriculture 2009)

The state consists of 23 districts. Three districts in the south of the state were included in this study (see Table 4).

Table 4. Basic information regarding area, number of blocks, population, and annual rainfall in the three studied districts within Andhra Pradesh

District	Area (km^2)	Total number of blocks	Population (year 2001)	Population density (Population/km^2)	Annual average rainfall (mm)
Anantapur	19 130	63	3 640 478	190	553
Kadapa	15 359	50	2 601 797	169	699
Nellore	13 076	46	2 668 564	204	1080

Source: **The National Portal of India (2010d) and APDES (2008)**

5.2.2. Tamil Nadu

Tamil Nadu is a smaller state than Andhra Pradesh, both regarding geographical size, 130 058 km^2, and population, 62.4 million. It is located in the south east part of the country; it is one of the most urbanized states with over 40 percent of the population living in urban areas. In spite of this urbanization, agriculture is the major occupation. (The National Portal of India 2010e, World Bank 2005b)

The two main sources of rainfall are, as in Andhra Pradesh, the South-West and the North-East monsoons. The South-West monsoon contributes approximately 35 percent of the total yearly rainfall, while the North-East monsoon is responsible for around 48 percent. The normal annual rainfall within the state is 959 mm, but the distribution varies between the districts. (Department of Economics and Statistics 2007)

Coimbatore and Tiruppur, which were visited during this study, are two of the 32 districts in the state.

Table 5. Basic information regarding area, number of blocks, population, and annual rainfall in the two studied districts within Tamil Nadu

District	Area (km^2)	Total number of blocks	Population	Population density (Population/km^2)	Average annual rainfall (mm)
Coimbatore	4 850	12	2 916 620	601	694.4
Tiruppur	5 106	13	1 917 033	375	NA

Source: Tiruppur District (2010), Coimbatore district administration (2010) and Department of Economics and Statistics (2007)

5.3. Implementation of Jatropha in the studied states

The initiation of large-scale Jatropha cultivation was encouraged by the national government and the National Mission on Biofuels to the state governments. At the state level, the district governments were asked to initiate implementation programmes for Jatropha plantations in their districts. The implementation in the studied districts was driven mainly by agricultural and rural departments, but in some cases also by local NGOs and private companies.

During the first phase of the National Mission on Biofuels the Planning Commission proposed to take up demonstration projects that would demonstrate the viability of all related activities. The experiences of the demonstration project would be the basis for the formulation of a project for the second phase of the mission. Twelve districts in Andhra Pradesh and nine districts in Tamil Nadu were proposed to initiate Jatropha plantation during the demonstration phase; all districts visited during this study are among these. (Planning Commission 2003)

5.3.1. Andhra Pradesh

Guidelines for the implementation of Jatropha initiatives came from the government of Andhra Pradesh, through the Rain Shadow Areas Development (RSAD) and the District Rural Development departments. The aim for the biofuel programme was to provide (RSAD 2006a):

- Alternative land use on under-utilized and fallow land, particularly in arid and drought-prone areas
- Sustainable source of income
- Employment in rural areas
- Energy security for the nation
- Easily available fuel in the rural areas.

The District Water Management Agency (DWMA), former Drought Prone Area Development Programme (DPAP), is a separate establishment of the District Rural Development Agency (DRDA), created to handle development of human and natural resources on a watershed basis. DWMA has the function of project directors for the bio-fuel programme at the district level, and is thereby the agency responsible for implementation and other practical matters *(*RSAD 2006b).

According to the guidelines the whole biofuel plantation work should be implemented under three different programmes, the National Rural Employment Guarantee Programme (NREGP), the Comprehensive Land Development Programme (CLDP), and the watershed programme, as all components of the biofuel initiatives fit under these programmes. DWMA is the agency responsible for monitoring and controlling of these programmes (DWMA 2007). Implementation of Jatropha plantation under these programmes has the result that only poor and marginal farmers were targeted, as the programmes aim at development of livelihoods for the rural poor.

5.3.1.1. Promotion and funds

In the promotion of Jatropha plantation the government of Andhra Pradesh announced the following incentives (RSAD 2006b):

- All farmers are provided with free seedlings.
- For installation of drip irrigation system a 90 percent subsidy (not exceeding Rs. 50000) is given to all farmers.
- Land preparation work is paid for under the Food for Work and Assigned Land Development Programme for eligible farmers.

Funds for the Jatropha plantations should be provided as follows (RSAD 2006a):

- Poor farmers of government assigned lands are provided 100 percent funding from NREGP, CLDP or watershed funds.
- All other farmers are provided 60 percent of unit cost from government funding, 40 percent is secured as bank loan.
- All Self-Help Groups (SHGs) maintaining plantations on government wasteland are provided 100 percent funding.

The funds should be released to the village councils, who will distribute the payments to the farmers (RSAD 2006a).

5.3.1.2. Bio-fuel plantation programme in Kadapa District

Kadapa is one of the studied districts in Andhra Pradesh. Kadapa has, unlike most other district, quite good documentation describing the Jatropha implementation programme and its intentions. This programme will therefore be described in more detail as an example of how implementation has been handled at the district level.

DWMA has defined Kadapa district as a rain-shadow region, which means that it receives less rainfall than other regions due to its geographical and topographical location. Water scarcity, infertile soils and low water-holding capacity affect the agricultural productivity and lands have been degraded and left fallow due to their unsuitability as cropland. Hence, incomes are low and poverty has become acute in the region. Also, DWMA acknowledged that energy supply is important in socio-economic development of the area, and that there is a need to secure independent production of renewable fuels. (DWMA 2005) With this background, in combination with a request from the state government of Andhra Pradesh to initiate a Jatropha programme[2], DWMA identified plantation of bio-fuel crops as a solution that could successfully contribute to improvement of livelihoods for rural farmers, restoration of degraded lands, and to self-supply of renewable energy. (DWMA 2005) As

[2] Dialogue with government official in Kadapa district, Andhra Pradesh

national state information showed good results for Jatropha cultivation, no trials at the district level were made, as is usually done prior to introduction of new agricultural crops[3].

In the agricultural year 2005-06, a project encouraging plantation of Jatropha on a total area of 4,000 Ha in all districts of Kadapa was launched. Seedlings were provided free of cost to the farmers. The project plan mentioned three models of plantation, the first on farmer's land under irrigated conditions, where drip irrigation at a 90 percent subsidy could be provided. This model promised the yields and incomes presented in Table 6.

Table 6. DWMA expectations on yield and gross income from Jatropha plantations in Kadapa

Year	Yield (kgs/ha)	Gross income (Rs)
3	2470	**5000**
4	4940	**10000**
5	7410	**15000**
6 and onwards	12355	**25000**

Source: **DWMA (2005)**

The second model did not include individual irrigation sources, but possibilities for drilling of community wells for pot irrigation of farmer's land, and the third model included other land under rain fed conditions. (DWMA 2005)

5.3.2. Tamil Nadu

In Coimbatore and Tiruppur, the districts studied in Tamil Nadu, the farmers were encouraged to start Jatropha plantations directly by district authorities or by private companies.

5.3.2.1. Government initiation

The District Rural Development Agency (DRDA) is the organ at the district level that manages and monitors the implementation of the anti-poverty programmes of the Ministry of Rural Development. In order to gather support and resources required for poverty reduction in the district, DRDA is expected to coordinate effectively with government departments, village council institutions, financial institutions, NGOs and technical institutions. (DRDA 2007)

In 2004, the DRDA of Coimbatore had a project for implementation of Jatropha cultivation, with the expectation to plant 1012 hectares of Jatropha in the district. No specific farmers were targeted. Instead, block-level workshops were organised to raise awareness and provide information about the crop. During these workshops, the focus was on barren, fallow, and rainfed land. (The Hindu 2004) Promised yields were 2470-7410 kg dry seed/hectare/year from year one, depending on cultivation inputs, with the possibility of yields as high as 12355 kg/ha/year later[4]. Interested farmers could turn to a Jatropha Information Centre that opened in connection with the Collectorate's office, where two agriculture graduates were available to guide farmers on the benefits of Jatropha plantation, raising and maintenance of seedlings, and buy-back facilities. A market for Jatropha seeds would be guaranteed by installation of oil production facilities in the districts, operated by SHGs (The Hindu 2004).

[3] Dialogue with government official in Kadapa district, Andhra Pradesh
[4] Dialogue with government official in Coimbatore, Tamil Nadu.

In promoting the establishment of Jatropha plantations, the district government of Coimbatore announced the following incentives (The Hindu 2004):

- Seedlings are distributed free of cost to farmers, especially to those in blocks covered under Drought Prone Areas Programme (DPAP) or Integrated Wasteland Development Programme (IWDP)
- Farmers are given a subsidy of Rs. 2.50 per seedling for plantation costs[5]

5.3.2.2. Company Initiation

As part of its promotion of biofuel production, the government of Tamil Nadu asked companies and NGOs within the state to express their interest for implementation of Jatropha plantation and oil production. Initially, four companies in the state were given permission to produce and process biofuels. One of these four, Bannari Amman Sugars Limited, has its base in Coimbatore (Paramathma 2006).

Bannari Amman Sugars Limited promoted Jatropha as a biofuel crop for afforestation to farmers having uncultivable or barren land. The company promised to provide training and technical assistance to farmers in Coimbatore and adjacent districts, and also to provide financial assistance by subsidies and access to bank loans. Furthermore, the company promised a market for harvested seeds, through oral and written buy-back agreements. Apart from contract farmers, Bannari Amman and their subsidiary company Shiva Distilleries Limited, established Jatropha plantations on company land in wind mill areas. To handle the outcomes of Jatropha cultivation, Bannari Amman invested in production facilities for production of 3000 litres of bio-diesel per day in their bio-diesel plant in Sathyamangalam, Tamil Nadu. (Bannari Amman Sugars Ltd 2010)

In addition to the farmers given permission for production and processing of biofuels, a number of companies were given permission to cultivate Jatropha through contract farmers. One of these was Coimbatore based RenuLakshmi Agro Industries Ltd., producer and promoter of biofuel technologies (RenuLakshmi Agro Industries 2009). RenuLakshmi established 243 hectares of Jatropha plantations through contract farmers, and invested in crushing facilities with a capacity of 3 tonnes of seeds per day (Paramathma 2006).

5.4. Overview of field study

During the field study, a total of 113 farmers and informants were interviewed in the previously described states Andhra Pradesh and Tamil Nadu, in order to assess the performance of Jatropha. New respondents were added to those in the earlier study. Table 7 gives an overview of how many of the respondents from the 2005-06 interviews were re-visited in the two states and how many new farmers were added to the sample.

[5] Dialogue with government official in Coimbatore, Tamil Nadu.

Table 7. Overview of the number of re-visited and new respondents in Andhra Pradesh and Tamil Nadu

	Andhra Pradesh	Tamil Nadu	Total
Number of respondents in the study performed in 2005	64	31	95
Number of respondent re-visited in 2010 (percentage of farmers visited 2005)	46 (72%)	15 (48%)	61 (64%)
Number of new respondents	36	16	52
Total number of respondents 2010	82	31	113

For a variety of reasons, not all farmers in the previous study were re-interviewed. In some cases the farm was visited but the farmer was not available; some farmers were not found due to lack of information in the earlier study; and in some cases long distances between scattered villages prevented visits.

Of the respondents in the earlier study, seven respondents belonged to the same household and same Jatropha plantation as other respondents and were therefore not included in the statistics. Hence, 106 respondents are included in the statistics and will from here on be the only respondents mentioned.

During the study 58 villages in 27 blocks in 5 districts within the two states were visited (see Table 8).

Table 8. Number of visited blocks, villages and respondents within the different districts in Andhra Pradesh and Tamil Nadu

State	District	Number of blocks	Number of villages	Number of respondents
Andhra Pradesh	Anantapur	1	5	17
	Kadapa	11	25	54
	Nellore	4	5	6
Tamil Nadu	Coimbatore	7	12	15
	Tiruppur	4	11	14
Total	5 districts	27	58	106

The respondents were divided into three different groups depending on the ownership of the land: private farmers, community land, and industry/research land (see Table 9). The respondents regarded as private farmers are farmers that have ownership rights to their land, but also farmers on land assigned by the government to a specific farmer to sustain his/her livelihood and state-owned land encroached by the farmer. The land is regarded as community land when the land has been assigned to a larger group of farmers or a village, for example land under the watershed scheme. Industry/research land is land owned and used by industries or non-private actors.

Table 9. Number of farmers within the groups private farmers, community land and industry/research land

	Private farmers	Community land	Industry/Research land	Total number of respondents
Andhra Pradesh	69	5	3	77
Tamil Nadu	27	0	2	29

6. Results

This chapter presents the results from the field study. First we provide background information on the respondents and how many of the respondents have continued or discontinued cultivation of Jatropha, continuing with a description of how Jatropha was introduced. Details regarding the Jatropha plantations are given, followed by an account of inputs to and outputs from the plantations. Drivers and barriers to continued cultivation of Jatropha and stated advantages and disadvantages are presented. The chapter concludes with a presentation of the results from biomass measurements.

6.1. Background information on the respondents

One of the objectives of the study is to assess the socio-economic impact of Jatropha cultivation in India; this requires information on the prevailing socio-economic status. Differences in socio-economic conditions can possibly also affect drivers and barriers to continuation of Jatropha cultivation and need to be taken into consideration when interpreting results. For socio-economic information the most interesting ownership group of the three mentioned in *5.4. Overview of the field study* is the private farmers.

In order to gain information on the socio-economic status of Jatropha farmers basic personal information regarding total landholdings, size of household, occupation, cattle population and education level was collected from the private farmers visited. Some of these factors, such as size of landholdings and literacy rate, are directly related to the farmer's economic standard, as discussed in *3.3.1. Connection to rural livelihood*. The results show large differences between the two states, which imply differences in economic standard. These differences are important for the interpretation of the results. What follows is a concise summary of the findings for the five categories.

The area of a farmer's total landholdings, in combination with other available income sources and household size, determines if a sufficient amount of food and other products needed for sustenance will be available for the farmer. It also limits how much of the landholdings can be used for other crops than food crops. In Andhra Pradesh 20 of the interviewed private farmers (29% of 69 respondents) owned 0.4 hectares of land or less; 21 (30% of 69 respondents) had between 0.5 and 2.0 hectares of land, and the percentage decreases as landholdings increase (see Figure 6). In Tamil Nadu it was more common among the respondents to have larger landholdings, no respondent having 0.4 hectares or less.

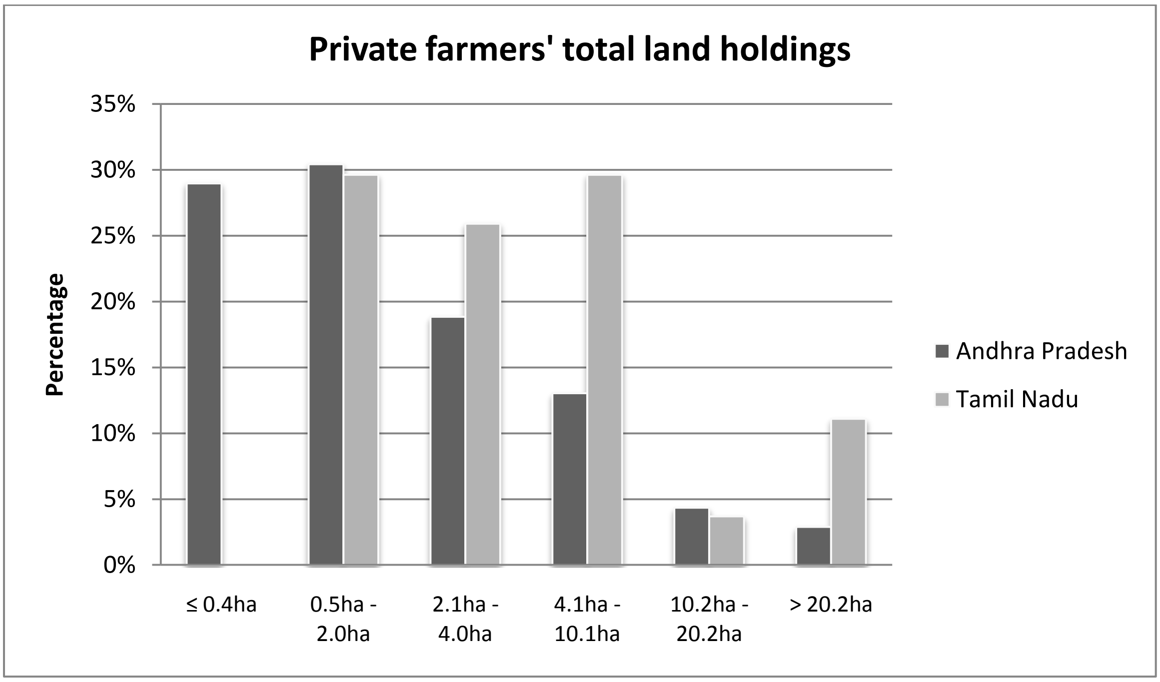


Figure 6. Private farmers' total land holdings

Regarding the size of the household the main portion of the private farmers in Andhra Pradesh, 62 percent, are more than 4 persons in each household. The majority of the private farmers in Tamil Nadu, 63 percent, are either 3 or 4 persons. For additional information, see Appendix IV.

The majority of private farmers from both states, 24 respondents (89% of 27 respondents) in Tamil Nadu and 37 (54% of 69 respondents) in Andhra Pradesh, report agriculture as their main occupation. In Andhra Pradesh the second most common main occupation at 38 percent is to work as a labourer, mostly within agriculture but also within other areas. Out of the 89 percent of the private farmers in Tamil Nadu having agriculture as their main occupation, 42 percent have subsidiary occupations, for example within the transport sector, as teachers, having small businesses, etc. The corresponding percentage for Andhra Pradesh is 19 percent (For more information, see Appendix IV).

Besides growing crops rural farmers can produce food products and gain incomes from possession of livestock. 43 percent and 67 percent of the private farmers in Andhra Pradesh and Tamil Nadu respectively also have cows, buffalos and/or goats/sheep.

In Andhra Pradesh 33 of the interviewed private farmers (48% of 69 respondents) state that they have no education, while only 1 respondent (4 % of 27 respondents) in Tamil Nadu report having no education. Low education level indicates low economic standard as discussed in *3.2.1 Connection to rural livelihoods*.

6.2.Continuation or discontinuation of Jatropha cultivation

Out of the 106 respondents 85 percent have discontinued cultivation of Jatropha (see Figure 7). Of the continuing 16 respondents 9 have continued with maintenance of their plantations; the other 7 respondents have stopped maintaining their plantations but have not removed the plants in order to use the land for other purposes. Reasons mentioned for keeping plantations or parts of plantations even though no outcome is expected are costs for removal of the plants and not having any plans for alternative uses for the land.

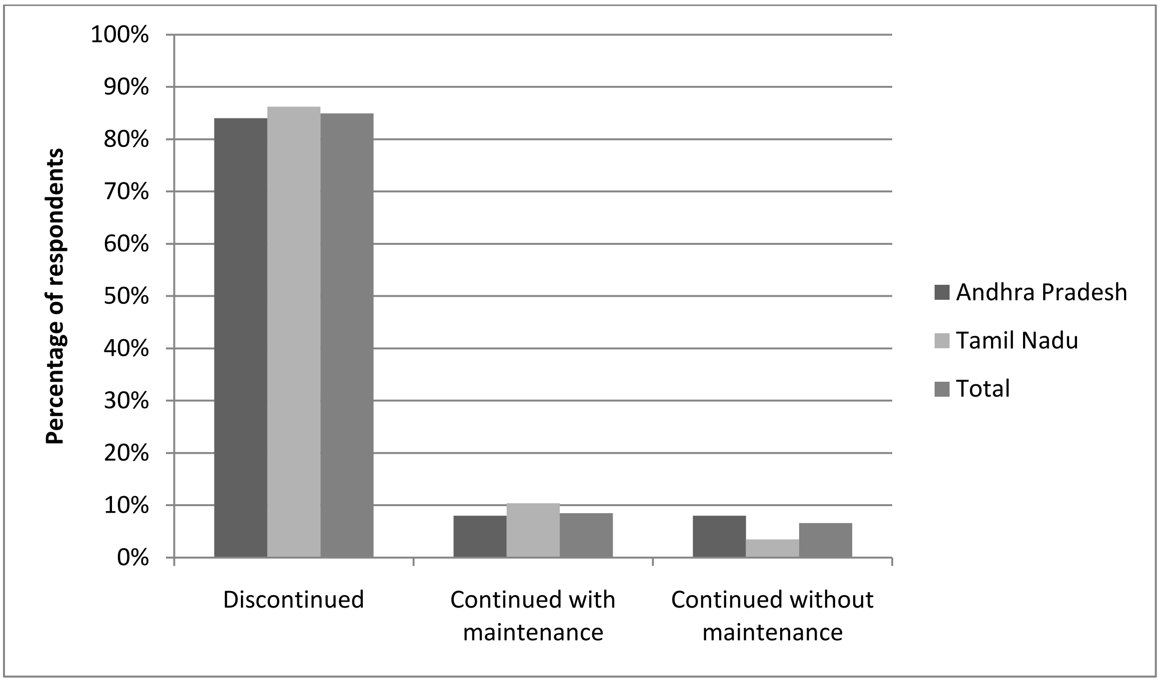


Figure 7. Percentage of the total number of respondents, and respondents at the state level, who have discontinued, or continued with or without maintenance, their Jatropha plantations

6.3. Introduction of Jatropha

The reasons given for taking up Jatropha cultivation vary. The answers were given to an open-ended question and were divided into 15 different motivational factors, which were further categorised into five categories: economic, ecological, environmental, socio-economic and other. In Table 10 the number of respondents who mentioned each motivational factor are shown. One respondent could mention more than one motivational factor (See Appendix V for categorisation criteria).

Table 10. Motivational factors included in the different categories and the number of respondents who mentioned each factor.

Economic		Ecological		Environment		Socio-economic		Other	
Income	**68**	Jatropha characteristics	**5**	Environmental interest	**2**	Watershed scheme	**4**	Government initiation	**16**
Loans	**17**	Use of wasteland	**3**	Pollution reduction	**2**	Energy supply	**1**	Demonstration	**4**
Subsidised agricultural facilities	**14**			Renewable energy	**2**	Job opportunities	**1**	Research	**2**
Financial subsidies	**10**								

Figure 8 shows the percentage of the total number of respondents who planted Jatropha for economic, ecological, environmental, socio-economic or other reasons, as indicated by their responses. Each farmer is only counted once in each category, even if he/she mentioned more than one motivational factor within the same category. The figure shows that the majority of the respondents within both states started for economic reasons.

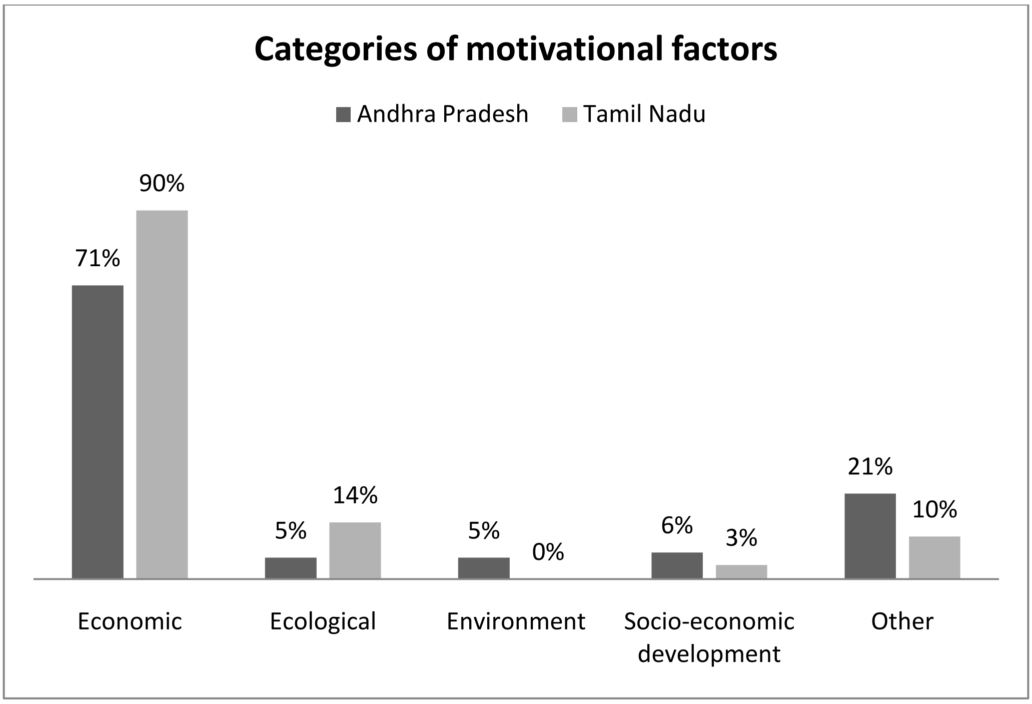
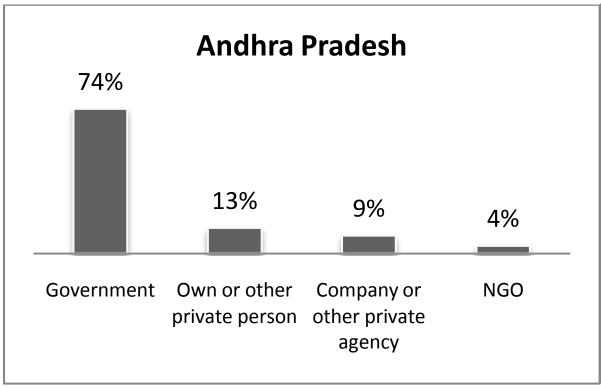


Figure 8. Percentage of the respondents from both states who mentioned motivational factors within each of the five categories.

Figure 9 shows who introduced the idea of Jatropha plantations to the farmers. For most of the respondents, both in Andhra Pradesh and in Tamil Nadu, the idea of initiating Jatropha plantations came from a government agency. Farmers have expressed some confusion regarding which government agency actually targeted them, but it usually belongs to the department of rural development or the agriculture department.



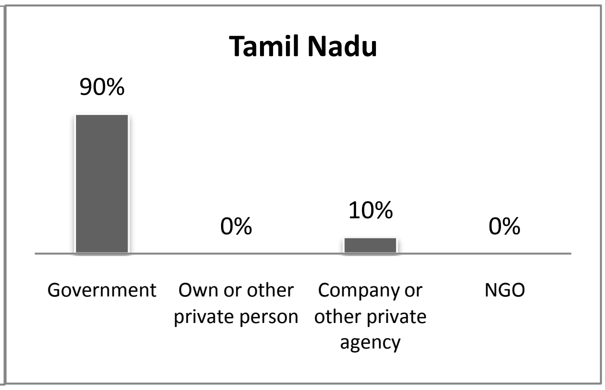


Figure 9. Source of idea to initiate Jatropha cultivation in the two states

The majority of the respondents planted Jatropha during Phase 1 of the National Mission on Biofuels, implying that the government would be responsible for plantation investments. Respondents planting Jatropha on research land received funds from the government, while many private farmers did not always receive what was rightfully theirs according to the national mission.

All private farmers planting Jatropha between 2003 and 2006 who were introduced to the idea by a government agency (72 respondents) have received free seedlings/stemcuttings. However, not all farmers received paid transport of seedlings/stemcuttings from the nursery to the farm. Apart from free seedlings/stemcuttings, most private farmers were promised subsidies or other forms of support, but not all received it. 35 and 48 percent of all private farmers in Andhra Pradesh and Tamil Nadu received some kind of subsidy or support, respectively, apart from free seedlings/stemcuttings. The subsidies came in the form of a financial subsidy based on plant number or a lump payment. The other support has consisted mainly of paid land preparation, pitting and planting, or of material inputs such as irrigation, fertilizers, manure, and pesticides.

Regarding information and training, 18 of the private farmers (26% of 69 respondents) in Andhra Pradesh and 6 (22% of 27 respondents) in Tamil Nadu claim to have received information or training. This came in the form of awareness meetings, training days, and village discussions where many of the farmers felt that the information given was inadequate.

6.4. Jatropha plantation details

The majority of the respondents planted Jatropha between 2004 and 2006 when the push from the government-initiated programmes was the most intense.

Out of 106 respondents four planted Jatropha using stemcuttings, two planted using seeds, for one it is unknown, and the rest planted using seedlings.

The land area planted with Jatropha varied among the respondents. Andhra Pradesh has a lower average Jatropha plantation area, nearly 2.7 hectares, than Tamil Nadu, where the average is 6.9 hectares. Four respondents have not had Jatropha plantations in blocks, but planted in bunds around plantation of other crops. See Appendix VI for details on Jatropha plantation areas.

In Andhra Pradesh, the land used for Jatropha was either cropland, forest land, land used for grazing or wasteland/barren land, based on the respodents' comments. 78 percent of the land used for Jatropha was cropland, and 17 percent was regarded by the respondents as wasteland or barren land. Four percent of the land was used for grazing, and one percent was considered forest land. In Tamil Nadu, the farmers did not use forest land: 93 percent was cropland, three percent wasteland/barren land, and three percent was used for grazing. Out of the 60 respondents in Andhra Pradesh who categorised their land as cropland, 9 respondents had partially or fully irrigated land. The corresponding figure in Tamil Nadu was 15 out of 27 respondents. The land regarded as cropland before Jatropha was used to grow a variety of food crops. However, this does not necessarily mean that the land is high-quality arable land since there are often discrepancies in what is regarded as cropland depending on who defines it.

The time the respondents continued their Jatropha plantations before the decision was made to discontinue varied. Figure 10 shows the lifetime of the plantations for the two states, indicating that the respondents in Andhra Pradesh in general kept their plantations for a shorter period of time.

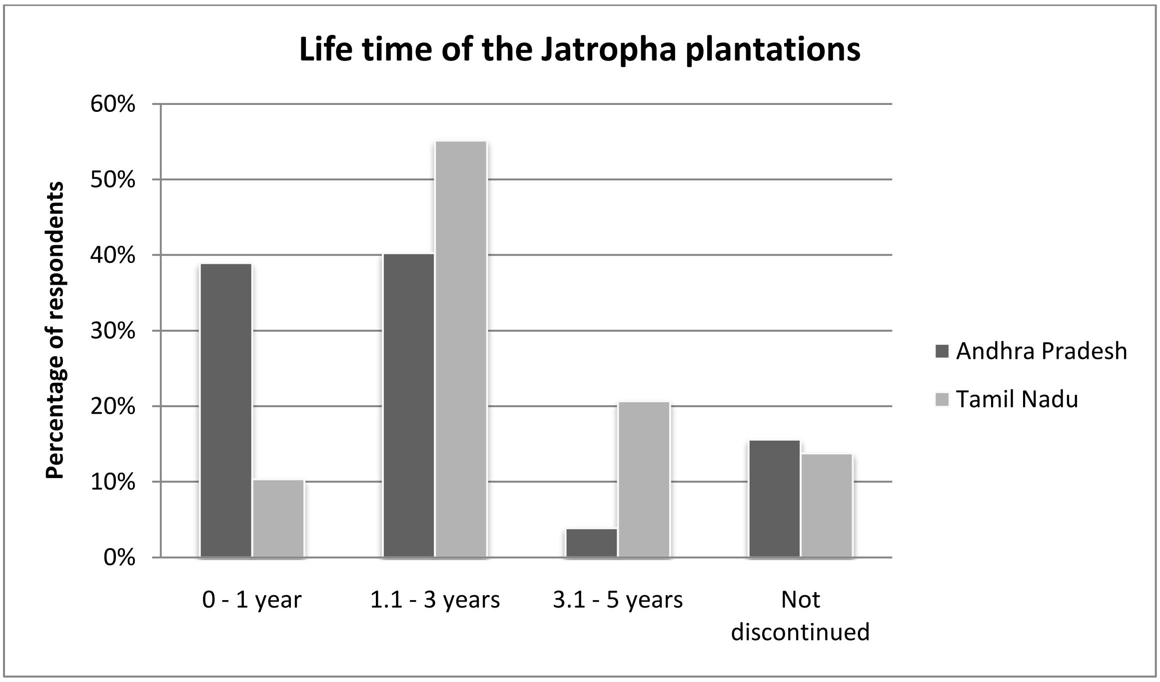


Figure 10. Lifetime of the Jatropha plantations. Percentage of respondents who kept their plantations for up to 1 year, 1.1-3 years, 3.1-5 years, and who have not discontinued their plantations.

Of the 90 respondents who discontinued their Jatropha plantations, 42 respondents currently use the land to grow other crops, mainly food crops; 44 respondents now have fallow land where Jatropha was cultivated; 1 respondent uses the land for grazing; and 3 respondents do not own the land anymore. Not all 16 respondents who have continued Jatropha cultivation (with or without maintenance) have kept the whole area that was initially planted with Jatropha; in some cases the area with Jatropha has been reduced and that area is either used to grow other crops or is fallow.

16 respondents (55% of 29 respondents) in Tamil Nadu have encountered problems with pests, while 14 (18% of 77 respondents) in Andhra Pradesh report pest problems. In Tamil Nadu mealy bug is the pest most frequently mentioned, also mentioned are green bug and white fly. In Andhra Pradesh the respondents who have experienced pest problems are less aware of what pests have been present, but they have experienced root rot problems, leaf webbing, and leaf folding. The pests have been identified as insects, worms, and termites.

6.5.Inputs to plantations

Even though Jatropha was characterized as a low-input crop, many respondents used inputs other than manual work, in the form of irrigation, fertilizers, manure, and pesticides/insecticides. (see Figure 11)

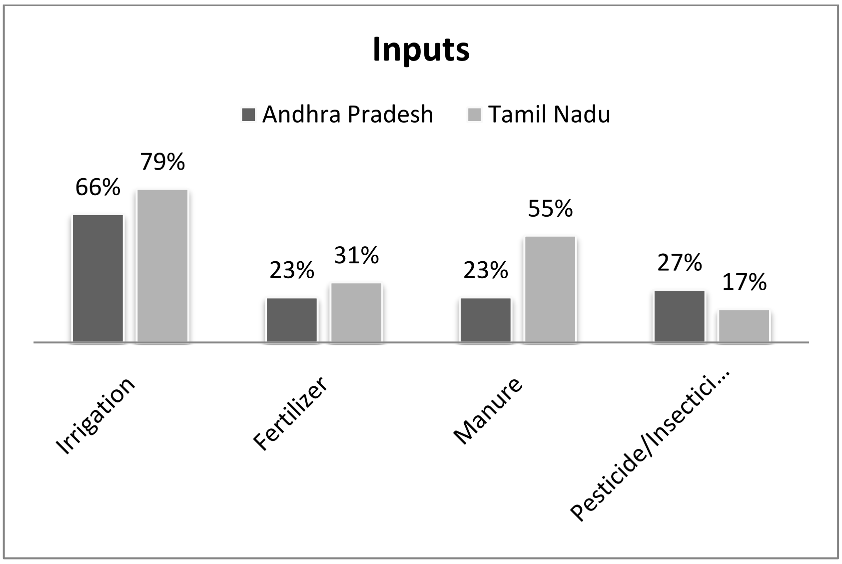


Figure 11. Percentage of respondents who applied different types of inputs. Note that amounts of inputs are not taken into consideration.

Irrigation of any frequency was/is used on 70 percent of the plantations. Different sources of water as well as sources of power to irrigate are used. The water is extracted from nearby ponds, rivers, and open wells or bore wells. The power used to extract the water was/is human power, electric pumps or diesel driven pumps. The irrigation systems are manual irrigation, drip irrigation, and canal irrigation.

27 respondents (25% of 106 respondents) applied inputs in the form of fertilizers to their plantations; the two main types of fertilizer are NPK and urea. Potash and different types of phosphate fertilizers were also used. Manure has also been applied to 32 percent of the plantations, in the form of biocompost, cow dung, neem powder, vermicompost, poultry manure, and sheep dung.

Gamexen powder was the most prevalently used pesticide. A few farmers received what they call "white powder" from government officials for application as pesticide but are not aware of what type of pesticide this is.

6.6.Plantation output and market

16 respondents (55% of 29 respondents) in Tamil Nadu harvested seeds from their plantations, compared to only 5 (6% of 77 respondents) in Andhra Pradesh. A total number of 21 harvested, 19 with known amounts, and the absolute amount of dry seeds harvested per field ranges from 2 kilos to 5 tons. Expressed in kilos per hectares and year, the resulting range is 2.5 to 2470 kgs/ha/year, with only two respondents harvesting more than 370 kilos per hectare and year.

The respondents were also asked what their expectations for their plantations were when they started, in terms of returns or yield. Out of the 21 respondents who harvested, 12 mentioned both realized harvest and expected yield prior to plantation. Only one of the respondents reached more than 50 percent of the expected yield (see Figure 12).

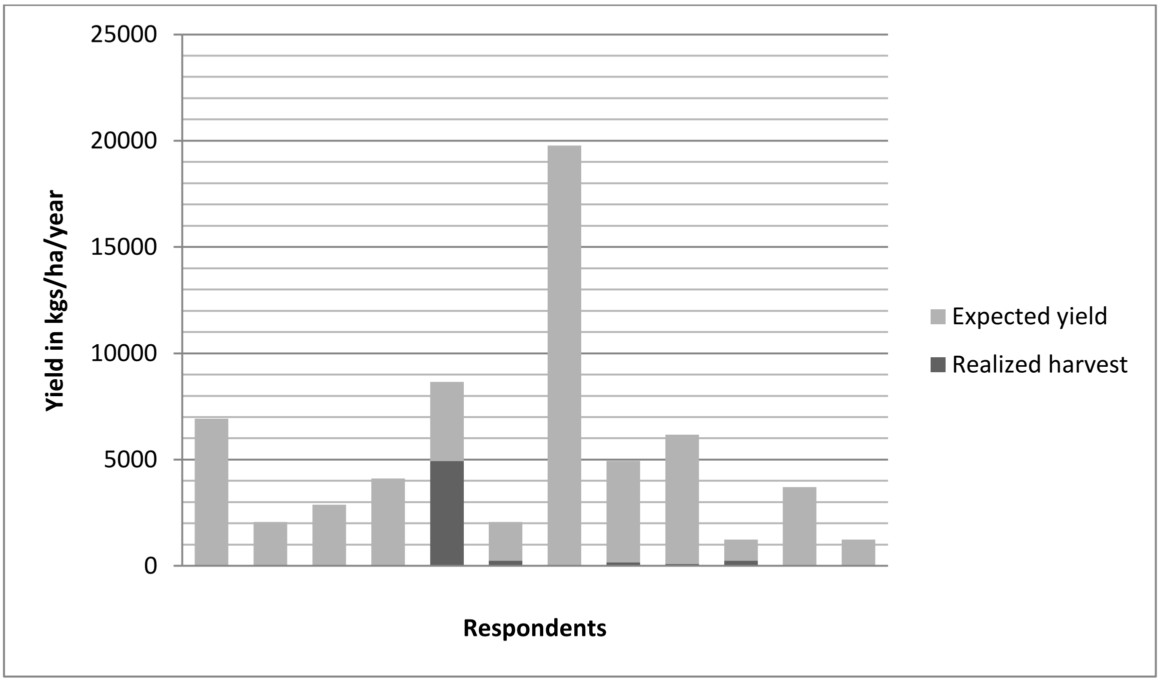


Figure 12. Expected yield with realized harvest as a portion of the expected yield for the 12 respondents who had both a harvest and an expected yield.

Only three of the 21 respondents who harvested actually sold their yield, receiving Rs. 6, Rs. 8, and Rs. 30 per kilo, respectively. The seeds were bought by a company, Bannari Amman Sugars, by the Tamil Nadu Agricultural University, or private individuals. The other respondents who had harvests simply kept their harvest or gave it away for free. Two respondents claim that they gave their seeds to private companies which promised them a price per kilo which would be put into their bank account, but money was never received.

To assess the respondents' awareness about the market before adopting Jatropha they were asked whether or not they had an agreement with anyone to buy their future harvest. 22 percent and 59 percent of the respondents in Andhra Pradesh and Tamil Nadu, respectively, claimed to have had an agreement with either a government agency or private actor when starting cultivating Jatropha. These agreements were either oral or written and the main content of the agreements was guaranteed purchase of the harvest either at a given price or at market price. A few respondents did not have an agreement but were instead promised, by a government actor, that with development of Jatropha production a market would be created. Who would actually buy the product and to what price was not mentioned.

6.7. Drivers and barriers to continued cultivation of Jatropha

Different drivers and barriers to maintaining Jatropha plantations were identified by asking the respondents what the reasons were/are for discontinuing/continuing.

A total of 16 respondents have continued cultivation of Jatropha with or without maintenance and have mentioned drivers that motivate them to continue. See Table 11 for the number of respondents mentioning each driver, illustrating which drivers within each category were the most significant, and Figure 13 for breakdown by category and state. A farmer can mention more than one driver, but is only counted once within each category (See Appendix VII for categorisation criteria).

Table 11. Drivers included in the different categories and number of respondents who mentioned each driver.

Economic		Ecological		Implementation	
Future income possibilities	**6**	Survives without maintenance	**6**	Demonstration	**4**
		Effect on other plants	**1**		

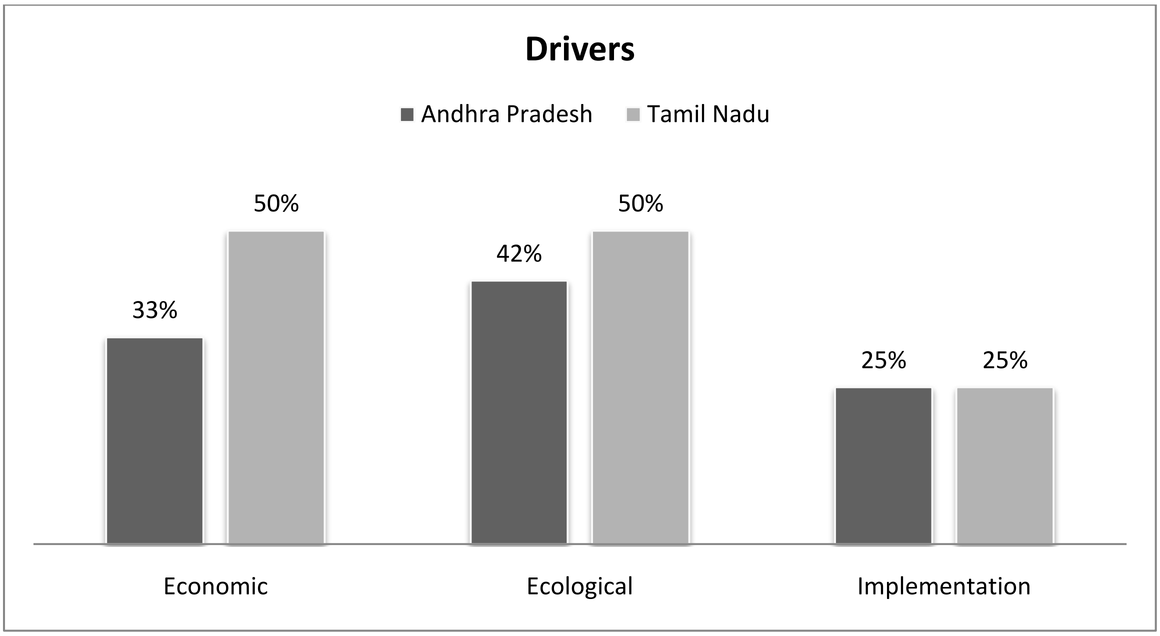


Figure 13. Percentage of the respondents from both states who mentioned drivers within each of the three categories.

90 respondents discontinued their Jatropha cultivation and mentioned the main barriers to continuation shown in Table 12. Once again, a respondent may mention more than one barrier within a category, but is only counted once within each category (see Figure 14). Some of the reasons mentioned are closely connected; sometimes it is difficult to distinguish a single barrier since one problem mentioned may be the root of another. For example, if low or no income is mentioned as a barrier to continued cultivation, this lack of income may be due to low yields caused by water scarcity (See Appendix VIII for categorisation criteria).

Table 12. Barriers included in the different categories and number of respondents who mentioned each barrier.

Economic		Ecological		Market		Knowledge		Implementation	
Income	**8**	Water scarcity and climate	**57**	No market	**2**	Maintenance and use	**3**	Unfulfilled promises	**10**
Labour problem	**6**	Yield	**12**			No interest	**2**	No support	**9**
Maintenance costs	**4**	Unsuitable land	**6**			Market	**1**	By order	**1**
Financial loss	**3**	Pests/diseases	**4**						
		Flooding	**3**						
		Jatropha characteristics	**3**						
		Cattle	**1**						

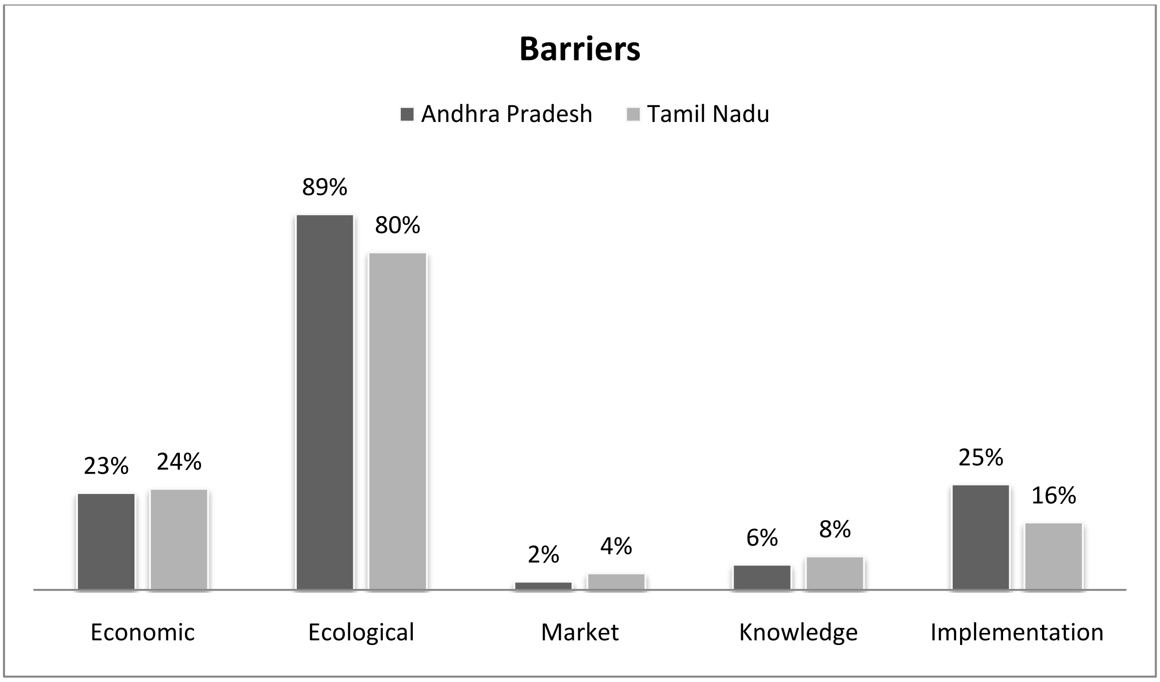


Figure 14. Percentage of respondents from both states who mentioned barriers within each of the five categories.

6.8.Stated advantages and disadvantages

Prior to the field study, potential advantages and disadvantages of Jatropha cultivation were identified for the individual farmer, his/her family, and their village.

The advantages identified were employment creation, increased income, use of wasteland, and increased energy supply. Out of the 106 respondents 15 respondents could mention advantages of cultivating Jatropha. 9 of these 15 respondents have discontinued their Jatropha plantations. Of the identified advantages, use of wasteland and employment creation were mentioned. Apart from the a priori identified advantages, one farmer also stated that his land was levelled and prepared for free so that he can now use it to grow other crops, and one farmer who cultivated Jatropha on occupied government land claimed that he gained stronger rights to continue to use the land.

The remaining 6 respondents who mentioned advantages continued cultivation. Two respondents mentioned advantages that they expect to gain in the future, and four could state advantages that had been achieved: use of wasteland, employment, and positive impact on other crops. One of the four respondents stated that Jatropha requires a minimal amount of water and maintenance and still produces seeds, that Jatropha has generated a high income due to high purchase prices, and that they have been able to provide local tribal communities with seeds that if planted and maintained can provide them with an income.

Additionally, some respondents said that they think that advantages can be achieved if irrigation is provided. Reconnecting to what was identified as advantages before the interviews, only employment creation and use of wasteland were regarded by some as advantages. Increased income and increased energy supply were not considered advantages with Jatropha cultivation by anyone.

Regarding disadvantages a greater percentage of the respondents had something to say, 84 out of 106 respondents. The a priori identified disadvantages were lowered income, competition with food production, reduction of community land, dependence on one crop, spread of pests to other crops, low yield, low profit, low price, pests, and no market. Out of these only one was never mentioned: reduction of community land. The respondents also mentioned several additional disadvantages.

Three disadvantages were mentioned by more than 30 percent of these 84 respondents: no or low income, no or low yield, and financial loss. Except for these three, five others were mentioned by over 10 percent: loss of income from other crops, lowered income, Jatropha's overrated drought tolerance, loss of labour days, and no market. Many of the issues brought up by respondents as disadvantages resemble the barriers identified in the previous section, but a few factors surface as disadvantages but not as reasons to stop cultivating, such as being scolded by neighbours and not being able to grow other crops on the land after Jatropha because it somehow has destroyed the soil.

6.9. Biomass and carbon stock

In this study 14 standing plantations were measured and their biomass was calculated. These plantations were planted on fallow land, wasteland, or land where other crops were grown. Replaced crops were commonly groundnut, horsegram, or rice, but on one plantation Jatropha replaced papaya and banana while on another it replaced other crops for research.

Calculations based on the measurements from the Jatropha plantations show the potential for carbon fixation in the biomass. Differences in agricultural conditions and age of plantations cause large differences in biomass and carbon content among the different locations. As mentioned in chapter 2, Jatropha plants mature after 4-5 years, and plantations younger than 4 years can be expected to increase more in biomass. Calculations for the mature plantations show that carbon uptake by the biomass ranges from 1.07 tC/ha to 5.03 tC/ha with one plantation having a larger uptake at 27.86 tC/ha. The annual sequestration rate ranges from 0.15 tC/ha/yr to 5.57 tC/ha/yr. For the younger plantations, those 2-3 years old, the carbon uptake is between 0.25 tC/ha and 1.35 tC/ha, giving an annual sequestration rate of between 0.13 and 0.45 tC/ha/yr.

Carbon fixation by Jatropha plantation in bunds is limited due to the low amount of plants available in the studied plantations; carbon content ranges from 0.014 tonnes to 0.070 tonnes per bund. Variation in the results is due to the varying number of plants in the studied bunds.

7. Interpretation of results

This chapter will interpret the results with the intention to address the purpose and research questions asked in the first chapter. It analyses the drivers and barriers to continuation of Jatropha cultivation and the impacts on the environment and socio-economic development. The chapter concludes with a comparison of Jatropha's performance in Andhra Pradesh and Tamil Nadu.

7.1. Drivers

When analyzing the drivers for continuing Jatropha cultivation, there is an important difference between those farmers who have actively chosen to continue and are still maintaining their plantations, and those who still have Jatropha plantations but who do not maintain these. The farmers who do not maintain their plantations have chosen not to remove the Jatropha plants, but do not expect any yield. The reasons for stopping maintenance are commonly low incomes or insufficient knowledge of the use of the crops, and the crops have survived even without maintenance. Some of these surviving plants are growing in bunds around plantations of other crops, and it seems like the collection of moisture in the bunds creates conditions where the Jatropha plants can survive without maintenance. The farmers who maintain their plantations have chosen to do so mainly because they still hope for incomes from future harvests or because the plantations were undertaken for demonstration or research.

The number of farmers who have continued cultivation of Jatropha is small, and these farmers are spread over several different land categories. They work under different agricultural and economic conditions and have a variety of reasons for keeping their plantations. Hence it is difficult to draw any general conclusions on the drivers for continued cultivation of Jatropha. What can be noted is that all farmers who have kept and maintained their plantations have the economic means to maintain non-profitable plantations. In the case of private farmers or companies who have continued they all have other sources of income, and incomes from Jatropha are considered additional. Where non-private actors have continued cultivation, the plantations are undertaken and continued for the purpose of demonstration or research and are not privately funded.

7.2. Barriers

The farmers who discontinued Jatropha cultivation mentioned many different reasons. These were divided into main categories.

7.2.1. Economic

The National Mission on Biofuels stated that all funds and investments during the demonstration phase of the Jatropha programme should be covered by the government. Still, farmers suffered severe financial losses due to unsuccessful cultivation of Jatropha.

One of the most important reasons for discontinuing cultivation of Jatropha was the low or non-existing economic returns from the plantations. In most cases there was no or very low yield, and hence no incomes from harvests to cover the cost for the plantation. Besides, many farmers substituted Jatropha for other crops and experienced loss of income from these crops. However, oral information on Jatropha cultivation encountered during the field study suggests that economic yield is reached at the earliest after three years, but most farmers have removed their plantations within three years after planting, hence before the time when economic yield could be expected. One explanation for this is that farmers could not afford to maintain plantations without any additional sources of income. Without maintenance, the plantations were in bad condition, which made it hard to expect that a good yield would ever be reached. With government subsidies or loans it could have been possible for farmers to keep their plantations until the time economic yields could be expected. Two out of the 90 farmers who discontinued their cultivation had been able to sell their harvest, but the combination of low yield and low purchase prices meant the income did not cover expenses.

Economic issues and lack of funds to maintain plantations were more apparent the poorer the farmer. The guidelines for the implementation for the Jatropha programme provided the opportunity to implement plantations under already existing poverty alleviation programmes, like the NREGP. As a consequence, a large part of the targeted actors, especially in Andhra Pradesh, were poor and marginal farmers. People living in poverty are constantly in acute need of cash to sustain their livelihood, and many farmers accepted to start Jatropha plantations just to get access to the financial subsidies and loans promised in the implementation programme. The farmers received seedlings to start their plantations, but in most cases other subsidies failed to reach the farmers. Without income, poor farmers could not afford to maintain their Jatropha plantations. 33 percent of the farmers removed their Jatropha within one year after planting, i.e., before even the first harvest would have been expected.

Farmers with larger landholdings that require employees for maintenance of plantations experienced labour problems a barrier to continued cultivation of Jatropha. It was mentioned that agricultural labour is too expensive, especially when incomes are low and cannot cover the labour cost.

7.2.2. Ecological

The main reason for choosing Jatropha for the large-scale programme for biofuel production was its agricultural characteristics: the suitability for cultivation on barren and fallow land, the low demand for inputs, and the resistance to pests and drought. Experiences from the plantations clearly show that Jatropha production has not been able to meet the high expectations.

Jatropha's drought resistance provided an opportunity for farmers on rainfed lands, who had been suffering from drought and had not been able to cultivate their land for years. Implementation was made under different schemes aiming at poverty alleviation and restoration of dry soils. But under harsh rainfed conditions, especially in the very dry and water scarce parts of Andhra Pradesh, Jatropha plantations failed to yield and could often not even survive. The single largest barrier to continued cultivation of Jatropha was water scarcity. The driest district visited in Andhra Pradesh, with an annual average rainfall of 553 mm, was Anantapur. According to existing Jatropha theory this water supply should be enough for survival of the plant, but it is far from the ideal situation for seed production, 1000 to 1500 mm. In many places subsidies for installation of irrigation facilities were promised, but in the water scarce areas, where even access to drinking water is a problem, it is not possible to install irrigation systems and use the valuable water for irrigation of biofuel plants.

Jatropha was promoted as a crop that could survive and yield on barren land without inputs of water and fertilizers. However, the crop proved not to meet expectations under these conditions, and it seems like inputs are needed for survival of the plantations on poor soils. 70 percent of the interviewed farmers mentioned that they have been using some kind of irrigation system, and 25 and 32 percent used chemical and biological fertilizers, respectively. Even with inputs Jatropha failed to give good yields, and the reason for this seems difficult for farmers and researchers to explain. As mentioned earlier, existing theory suggests an annual yield per hectare of 0.1 to 15 tonnes.

Comparing this to the realized harvests of the 19 respondents who have had a harvest of known amount, only 6 respondents' harvests have reached the theoretical range, all these in the lower part of the range.

Another problem experienced, mainly by farmers in Tamil Nadu, was pest attacks. In some cases the pest attacks were mild and could be solved by application of pesticides, but sometimes the pest attacks were more severe and badly affected plant growth and forced removal of plants. This contradicts the belief that Jatropha should be more resistant to pests than other crops. The most prevalent pest, which caused the most severe impacts, was the mealy bug. However, according to farmers and government officials in Tamil Nadu the state experienced an unusually large attack of mealy bug in 2006-07 that affected most crops in the area. Jatropha may still be more pest resistant than other crops, but the resistance might not be enough when facing a severe attack and as suggested in literature its pest resistance may decrease in monoculture plantations.

Many of the ecological issues experienced could possibly have been discovered and avoided if studies of Jatropha on existing soils had been made prior to implementation. It is common practice in the studied districts to make a technical assessment and present a scientific protocol before the release of new crops to ensure compatibility with prevailing conditions. In the case of Jatropha no trials were made, instead district authorities and farmers were provided with information from state governments.

7.2.3. Market

One of the problems mentioned as a barrier to continued Jatropha cultivation was a market problem. The National Mission on Biofuel did not provide any clear plans for marketing Jatropha biodiesel, and no structure for communication between farmer and biodiesel producer to facilitate purchasing. As the Jatropha programme was driven by targets and government goals rather than by demand for a product, explicit plans for market development were needed. During promotion and implementation government representatives promised that a market for the seeds would develop along with development of the plantations.

Unsuccessful yields and low supply of harvested seeds did not provide any incentives for actors to invest in facilities for oil extraction and transesterification. Consequently, the market for seeds was very limited. Even though 32 percent of the respondents had oral or written buy-back agreements with the government or with local companies, farmers who were able to harvest did often not have any knowledge of the existing market structures and possibilities. In several cases the interviewed farmers had not been able to sell their harvest, but had kept it or thrown it away, not knowing what else to do. In nearly all cases, the Jatropha production system only reached the cultivation stage, limiting the possibilities to explore the production stage of the system.

Bannari Amman was one of the companies who invested in facilities for production of biodiesel and purchased seeds from their own plantations or contract farmers. But transesterification proved non-profitable in small quantities and the company decided to only take production to the level of oil extraction. It is unclear how large the production of oil actually has been, and if the company has kept their promises to purchase seeds from the farmers.

7.2.4. Knowledge

In several cases farmers expressed insufficient knowledge concerning the maintenance of their Jatropha plantations, and even concerning what the crop is used for. It seems the government extension services failed to provide the farmers with a sufficient amount of knowledge. Only 25 percent of the private farmers mentioned that they received any technical training or information, despite the promise of education and information to all concerned parties. As mentioned earlier, implementation of new crops is usually preceded by studies of plantations under prevailing conditions, to develop a package of cultivation practices for provision of scientific advice to concerned farmers. In the case of Jatropha implementation during the first phase of the national mission no such studies were done. Instead district level authorities trusted information from the national and state level, and provided this to the farmers. There was also insufficient knowledge about the market, as discussed previously.

Farmers also expressed a lack of interest in Jatropha cultivation. Possibly, this derives from the situation where farmers took up Jatropha plantations just for the access to the financial incentives promised during the implementation of the programme, and there was no interest in learning about the maintenance and use of Jatropha.

7.2.5. Implementation

The National Mission on Biofuels stated that investments in the implementation of Jatropha production should be made by the government. This would be ensured by subsidies and loans to the farmers. From the interviews it is clear that the incentives promised during the implementation programme often did not reach the farmers. Many farmers mentioned a lack of government support or unfulfilled promises as barriers to continued cultivation of Jatropha.

It is not clear what the reasons are for this lack of government support and failure to fulfill promises. An official from Kadapa district government, who was involved in the implementation of Jatropha in 2004-05, mentioned that according to government policy, subsidies are only given to projects considered to be successful, and since the Jatropha plantations failed to meet the expectations the government discontinued the subsidies[6]. The same official also described an inability to utilize supporting schemes due to unawareness and lack of outreach to farmers regarding support opportunities. Also, India has a severe problem with corruption and large parts of public subsidies fail to reach the intended receivers (Luce 2006). However, the connection between corruption and the unfulfilled promises in the studied states has not been investigated and will not be further discussed in this report.

The Jatropha programme was not planned properly before implementation: no follow-up or further contact with the farmers was planned. The lack of support from the government disappointed many farmers, who feel betrayed by the authorities who encouraged them to grow Jatropha but then showed no interest and provided no additional support. This can possibly lead to mistrust towards the government. In the same way the district authorities feel betrayed by national and state government who pressured them to implement an unsuccessful programme and convince poor farmers in their areas to start cultivation that has lead to severe financial losses. Several officials encountered during the field study have expressed that they feel bad for advocating Jatropha cultivation to the farmers.

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[6] Dialogue with government official Kadapa, Andhra Pradesh

7.3. Environmental and socio-economic impacts

Before the start of the Jatropha programme the expectations were high for the project to contribute to environmental and socio-economic development in India, especially in the poor rural areas.

7.3.1. Environmental

One of the main results expected from biodiesel production was a reduction of greenhouse gas emissions from replacing some of the fossil diesel use. As only a small amount of Jatropha biodiesel has been produced, the reduction of emissions is very limited.

As discussed in Chapter 2, positive environmental impacts depend on low-intensity cultivation practices. Jatropha was promoted as a no or low-input crop, but interviews have shown that plantations need irrigation and fertilizers for survival and growth, and a majority of the farmers have used one or more types of inputs.

Almost 70 percent of the farmers in Andhra Pradesh have provided irrigation to some extent to their Jatropha plantation. The studied districts of Andhra Pradesh are among the most water scarce parts of India, and use of water for irrigation puts severe stress on the scarce resources. Irrigation for biofuel production generates conflicts with other uses of water, for example for household purposes and other agricultural activities like food production. The share of farmers using irrigation is even higher in Tamil Nadu, around 80 percent, but the water resources are not as scarce. Apart from increased stress on water resources, irrigation has environmental impacts through energy requirements for installation and operation of mechanized irrigation systems. Also the use of fertilizers has negative environmental impact due to energy needs in the production phase and pollution to water and soil.

Compared to values mentioned in the literature review, carbon uptake in the studied plantations is low. A study reporting a carbon uptake of 25 tC/ha was performed on rainfed Indian wasteland, which implies that this should be a reasonable value for the studied plantations to reach as the prevailing conditions are similar. However, only one plantation was found to lie within the range of the values in the literature review. The rest of the mature plantations range between 1.07 and 5.03 tC/ha compared to the reported uptake of 25-40 tC/ha. For the younger plantations, a carbon content of 5 tC/ha and annual sequestration rate of 1.43 tC/ha/yr was reported for a plantation on infertile Indian soil, i.e., on conditions similar to the studied plantations. But, as for the mature plantations, the studied plantations do not reach the level of the reported values; the highest calculated carbon content is 1.35 tC/ha and the highest annual sequestration rate is 0.45 tC/ha/yr. The low carbon contents in the measured plantations imply that Jatropha may not be efficient for carbon fixation. However, the measured plantations have usually replaced plantations with small biomass, implying that even if the standing Jatropha biomass does not reach the levels reported in the literature the land now has the potential to take up more carbon than earlier.

Positive environmental impacts were also expected from cultivation of the crops, by provision of soil nutrients, reduction of soil erosion and prevention of land degradation. As most discontinued plantations were removed at an early stage it is difficult to determine if the plantations had succeeded in providing soil nutrients in the short time span, and as few plantations still exist the expected impacts on soil erosion and land degradation have not been realized.

7.3.2. Socio-economic

Expectations were high for Jatropha to contribute to the socio-economic development of poor areas in rural India, mainly by offering farmers additional income sources, but also by creating employment opportunities and enhancing rural energy supply.

When estimating land area available for Jatropha plantation, the Planning Commission identified 13.4 MHa of land suitable for the purpose. The identified land areas were on land classified as wasteland, not suitable for cultivation of other crops to avoid competition with food production. Plantation of Jatropha was expected to help restore soil nutrients and rehabilitate barren and uncultivable land. Still, 78 percent of the famers in Andhra Pradesh and 93 percent in Tamil Nadu planted Jatropha on cropland, and removed plantations of food crops for Jatropha or planted on land which is suitable for other crops. One reason for this could be a gap in perception of what is considered wasteland, the government targeted farmers on land they classified as wasteland, while the farmers viewed it as cropland. The reason could also be that economic incentives, promises of higher incomes and pressure from the district authorities pushed farmers to substitute Jatropha for their food crops. The district authorities may have been influenced to implement Jatropha on cropland due to lack of information on the national mission and pressure for fast implementation from national and state governments. More emphasis is put on the implementation of biofuel crops on wasteland in the new biofuel policy announced in 2008.

One of the expected positive impacts from the Jatropha programme was employment generation in rural areas. It is difficult to estimate the realized number of generated jobs, but it is clear that the number estimated by the Planning Commission has not been reached. There were plans to plant Jatropha on government and community land, which would have created jobs in planting and maintenance. But in the studied states most of the plantations were or are located on private land. Some jobs were generated in conjunction with plantations on private land, but in most cases the landholdings are small and there is no need for additional labour from outside the household. In some cases labourers were employed for land preparation and maintenance, but failing yields have minimized the need for labour for seed collection and production. Farmers have chosen to remove plantations rather than employ agricultural labour, since incomes from the plantations are too low to cover labour expenses.

7.4. Comparison of the two states

The respondents in Andhra Pradesh and Tamil Nadu planted and maintained their Jatropha plantations under somewhat different conditions. The implementation of the National Mission on Biofuels differs to some extent between the states as well as the socio-economic situation of the majority of each state's respondents.

The most significant difference between the programme implementation in Andhra Pradesh and in Tamil Nadu is the way in which it was introduced to the farmers. In Andhra Pradesh the initiative was more or less pushed out onto farmers without providing sufficient information on available financial funding and maintenance practices while in Tamil Nadu information was provided to interested farmers at workshops, village discussions and at a Jatropha Information Centre.

Comparing the respondents in Tamil Nadu and Andhra Pradesh, Andhra Pradesh has a higher percentage of respondents without education, a higher percentage of households containing more than 4 persons, a higher percentage of respondents dependent on agriculture because few have subsidiary occupations not related to agriculture and the average total landholdings is lower. Based on this study the average household in Andhra Pradesh therefore has a smaller land area to sustain the livelihood of a larger family, with less income from non-agricultural occupations compared to the average household in Tamil Nadu. This indicates a stronger economic situation in Tamil Nadu.

These could be reasons that, for example, a larger percentage of the respondents in Tamil Nadu have had a harvest – Jatropha was more often planted because of an independent interest, with greater knowledge of available funding and of when to expect the first harvest. With a stronger economic situation, and available funding, the respondents were able to maintain the plantation until the first harvest.

8. Conclusions

The conclusions reached here, based on our interpretations of the results, provide answers to the research questions posed in Chapter 1.

- To what extent has Jatropha been able to meet the high expectations put on its performance as a biodiesel crop?

Jatropha has not been able to meet the expectations of those involved in the Jatropha programme in southern India. 85 percent of the interviewed farmers have discontinued cultivation of Jatropha due to poor performance. Jatropha biodiesel production was advocated based on the idea that Jatropha could be cultivated on degraded or barren land, that demand for inputs was low, and that the crop was resistant to drought and pests. Experiences in the field show that Jatropha has failed to survive and/or grow on poor soils and that a majority of the farmers planted Jatropha on cropland. The plantations have not been able to tolerate drought as well as expected, and pest attacks have occurred in several cases. Farmers have experienced that the crop requires inputs for survival and growth and have used irrigation, fertilizers, manure, and pesticides. Even when planted on fertile land and provided inputs, Jatropha did not produce a harvest or else not a sufficient yield.

- What motivational factors act as drivers and barriers to continued Jatropha cultivation for farmers?

Few of the studied farmers have continued cultivation of Jatropha. The main driver for private farmers who maintain plantations is the hope for future income. The reason for continued cultivation *without* maintenance is that those plantations survive even if they are not maintained. The farmers who still have their plantations all have the economic means to keep plantations that do not generate sufficient income. For private actors this implies having additional income sources not related to the land used for cultivating Jatropha. For non-private actors funds are provided from external sources and the plantations are maintained for non-profit purposes, like research and demonstration.

The main barriers to continued cultivation of Jatropha are connected to ecological problems experienced by the farmers. The most significant problem is that Jatropha has failed to meet expectations on drought resistance, and farmers are experiencing water scarcity as a main barrier to continued cultivation. Water scarcity leads to non-survival of plantations or failing yields. Farmers experience insufficient yields as a barrier to continued cultivation of Jatropha even when inputs are applied, as plantations have generated no or low yield even with irrigation and fertilizers.

Problems in the implementation of the Jatropha programme have also been experienced as barriers to continued cultivation. The main problem is that farmers have not received subsidies and other support that was promised during the implementation process.

- What are the environmental and socio-economic impacts of Jatropha biodiesel production?

The expected positive environmental impacts from the use of biodiesel have not been achieved given that very little biodiesel from Jatropha has been produced in the studied areas. Further, the environmental advantages of the Jatropha plant—the low use of inputs and the ability to reclaim barren and unused land—have not been realized. Application of inputs in the form of mechanical equipment, irrigation, fertilizers, and pesticides has been necessary for growth and survival of the plantations, which contributes to energy use and emissions. As few plantations still exist the restoration of poor soils and degraded land has been limited, as well as the ability to store carbon.

The positive socio-economic impacts expected from implementing the Jatropha programme have not been realized. Instead of gaining additional income from Jatropha plantations, farmers have experienced financial losses and reduced income. Some job opportunities were created in the initial stage of cultivation, when preparing land and planting, but the Jatropha production system has not generated nearly as many job opportunities as was estimated. 82 percent of the farmers have planted Jatropha on cropland, which has entailed competition with food production.

9. Discussion

During this project we encountered interesting issues in need of further research. This chapter discusses the main topics among these.

One of the main problems encountered during Jatropha cultivation is the failure to reach satisfying yields. To some extent the explanation can be that the expectations on Jatropha characteristics, such as drought resistance and ability to grow on degraded soils, have been too high and that cultivation under poor conditions has failed. But experiences in the studied districts show that even if inputs are applied and plantations are properly maintained the yields have not reached expected levels. The field study has failed to provide any explanation to this problem. When questioned about reasons for yields failing, neither farmers, researchers, nor government officials were able to provide clear answers. They have mentioned reasons such as unsuitability of soil and climate, poor maintenance, etc. One theory, provided during an informal discussion with a representative of an institute involved in Jatropha research, is that cross-pollination by air has created hybrids of different Jatropha varieties that do not possess the agricultural characteristics of *Jatropha Curcas*. This would mean that what the farmers actually grow on their fields is not *Jatropha Curcas* but a variety that is not as resistant and high-yielding as the intended crop. There is still hope for biodiesel production from Jatropha, but more scientific research on Jatropha characteristics is needed, and development of high-yielding and resistant varieties is required, for Jatropha to become a successful biodiesel crop.

The planning and implementation of the Jatropha programme were poor, but it is difficult to say if a better planned programme could have enhanced the outcome, since the ecological problems seem to be the main reason for discontinuation of Jatropha cultivation. However, with better planning and implementation the severe consequences and financial losses for the farmers could have been avoided. If studies under prevailing conditions had been made prior to implementation, the ecological problems could have been discovered and the government departments could have avoided promotion of an unsuccessful crop to the local farmers. Pre-studies could also have allowed for better-performing varieties to be developed. Better information on Jatropha and its characteristics would have enabled better extension services to the farmers, and the farmers need not have been insufficiently knowledgeable about maintenance and use. It seems like the government of India has realized that the original implementation was not optimal, as they aborted the National Mission on Biofuels and replaced it with a new policy.

One example that clearly illustrates the poor planning of the Jatropha programme is the gap between calculated land requirement and the planned cultivation in the first phase of the programme. In the National Mission on Biofuels, the Planning Commission stated that a blending target of 5 percent should be reached by 2006-07. To reach this, they calculated a demand for 2.62 million tonnes of biodiesel, which would require 2.19 MHa of land for production. At the same time the national mission stated that the first phase of the Jatropha programme should be a demonstration project, where 0.4 Mha of Jatropha plantations would produce 0.48 million tonnes of biodiesel. Hence, with the planned implementation there was no chance to reach the stated goals.

Another implementation issue is the targeting of poor and marginal farmers. The idea was for Jatropha to give an opportunity to use and restore their poor land and to provide additional incomes to the household. But instead these farmers have suffered the most since they have the farms with the least favourable conditions, the smallest possibility to afford maintenance of plantations and wait for incomes, and will suffer the most from economic losses.

To implement the Jatropha programme the government used the opportunity to target farmers through existing poverty alleviation initiatives and to use funds available in these initiatives. Consequently, funds supposed to enhance the livelihoods in poor rural areas have been used for an unsuccessful project that in many cases has been counter-productive to the objectives of the initiatives and has aggravated the situation for targeted farmers. Possibly, through these other initiatives, the funds could have alleviated the situation for the rural poor.

Hopefully other states can learn from the mistakes made in Andhra Pradesh and Tamil Nadu. The state of Karnataka has recently started a Jatropha programme where the focus is not only on large-scale plantations, but also on implementation in bunds and backyards. This strategy may not render any large-scale positive environmental impacts, but can contribute to local socio-economic development by offering an additional income stream to the farmers. A Biofuel Park for research and development of biofuel crops is being set up in the Hassan district in Karnataka.

Results in Andhra Pradesh and Tamil Nadu made clear early on that it was not feasible to reach the National Mission on Biofuels blending target of 20 percent by 2012. With the reported poor performance of Jatropha and the lack of research and technical information, the National Biofuel Policy target for biodiesel produced from Jatropha does not seem likely to be feasible either. Other feedstocks will be required to reach 20 percent biodiesel blending by 2017 biodiesel. Jatropha can possibly contribute, if further research and development can provide an efficient production system.

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Appendix I. Factors affecting poverty and hunger

Tables from reference: IARI - Indian Agricultural Research Institute (2010) *Agriculture Policy: Vision 2020.* http://india.gov.in/sectors/agriculture/policies_plans.php (2010-05-17)

Table 5. Incidence of hunger and poverty by farm size in rural India

Land class	Percent of population	
	Hungry	Poor
Land less	49	54
<0.5 ha	32	38
0.5-1ha	24	27
1.0-2ha	17	19
2.0-4ha	12	14
>4ha	12	13

Source: IARI-FAO/RAP study (2001)based on 50th NSS Round(1993-94)

Table 7. Impact of irrigation on alleviation of hunger and poverty in India

Irrigated area (%)	Percent of population	
	Hungry	Poor
Rainfed	33	35
<20	20	22
20-50	22	23
50-80	18	24
>80	19	26

Source: IARI-FAO/RAP study (2001)based on 50th NSS Round (1993-94)

Table 8. Impact of livestock on alleviation of hunger and poverty in India

Livestock	Percent of population			
	Rural		Urban	
	Hunger	Poor	Hunger	Poor
None	36	28	43	55
Cow	31	25	29	42
Buffalo	26	18	20	33
Cow & buffalo	14	8	7	4

Source: IARI-FAO/RAP study (2001)based on 50th NSS Round (1993-94)

Table 9. Impact of literacy on alleviation of hunger and poverty in India

Literacy level	Percent of population			
	Malnourished		Below poverty level	
	Rural	Urban	Rural	Urban
Zero	36	28	43	55
Below Primary Level	31	25	29	42
Above Primary Level	26	18	20	33
Graduate and Technical	14	8	7	4

Source: IARI-FAO/RAP study (2001)based on 50th NSS
Round (1993-94)

Appendix II. Wasteland categorisation

Category	Area (2003) (MHa)
Gullied and/or ravinous land	1.90
Land with or without scrub	18.79
Waterlogged and marshy land	0.97
Land affected by salinity/alkalinity-coastal/inland	1.20
Shifting cultivation area	1.88
Underutilized/degraded notified forest land	12.66
Degraded pastures/grazing land	1.93
Degraded land under plantation	0.21
Sands-inland/coastal	3.40
Mining/industrial wastelands	0.20
Barren rocky/stony waste/sheet rock area	5.77
Steep sloping area	0.91
Snow covered and/or glacial area	5.43
Total wasteland area	**55.25**

State/district	Area (MHa)	% of total area
Andhra Pradesh	**4.53**	**16.46**
Kadapa	0.45	29.45
Nellore	0.29	21.80
Ananthapura	0.36	18.72
Tamil Nadu	**0.88**	**14.58**
Coimbatore	0.14	18.85

Source: DoLR (2004)

Appendix III. Interview guide

INTERVIEW ANSWERING SHEET – PRIVATE LAND

I. Socio-economic condition

Name of village :
Date of obn.:
Name of farmer :
Participated in earlier study: YES / NO
Still growing Jatropha: YES / NO

Education level :

Size of household	Male	Female	Children	Total

Occupation	Main	Subsidiary	Others

Crops grown	Land holding (acre/ ha/ local unit)			
	Irrigated	Rain fed	Other land	Total
			SUM:	

Cattle population	Cow	Buffalo	Sheep/Goat	Total

II. Jatropha plantation details

Why did you start growing Jatropha?

…………………………………………………………………………………………………
……………………………………………………………………………………………

What are the reasons for continuing/discontinuing growing Jatropha?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………………………………………………………………

If discontinued:

When	
Whose decision	
Current use of land	

	I Plantation	II Plantation	III Plantation
Year planted			
Jatropha species			
Area brought under Jatropha (local unit or ha/acres)			
Who owns the land that you grow Jatropha on? -Agreements with landowner			
Use of land prior to Jatropha - Land category brought under Jatropha (Fallow land /Dry cropland/ Irrigated cropland/ Others) -Soil (hard/loose, color)			
If cropland: -what crops were grown -crop grown for how many years?			
Who initiated the idea of Jatropha? - Purpose - Still involved			
Source of fund	Govt./ Personal / Bank loan/Other	Govt./ Personal / Bank loan/Other	Govt./ Personal / Bank loan/Other
What support have you received from Govt. or any other agency? -Still receive it (yes/no)			

Did you see any risks with growing Jatropha?			
Intercropping (Yes/No) - With what			
Survival rate - Reasons for non-survival			
Pest attacks - What type of pest - Affecting (plant growth, seed production)			

III. Inputs into Jatropha Plantations

	I Plantation	II Plantation	III Plantation
Cost of land preparation -Animal power -Tractor -Human power (days)			
Cost of -pitting -planting			
Source of -Seed -Seedling - Stem cutting			
Cost of -Seed -Seedling - Stem cutting			
Germination rate			
Cost of cultural operation -Weeding -Pruning -Soil work -Mulching			
Irrigation -Frequency during summer -Frequency during rains			
Source for irrigation -Diesel engine capacity -Electric pump capacity -Human power -Cost			
Fertilizer application -Type -Quantity -Frequency -Cost of fertilizer / year -Labour cost			
Manure application -Source -Quantity -Frequency -Cost of manure -Labour cost			
Insecticide/ pesticide application -Name			

-Quantity -Frequency -Cost of chemical -Labour cost			
Cost of harvest (fruits/seeds) -Labour -Transport -Machinery -Processing(Seed dry)			
Total cost of harvest			

IV. Returns or Outputs from Jatropha Plantations

	I Plantation	II Plantation	III Plantation
Area			
Year I -No of harvests (month) -Quantity(green/air dry) (kg/quintal)			
Year II -No of harvests (month) -Quantity(green/air dry) (kg/quintal)			
Year III -No of harvests (month) -Quantity(green/air dry) (kg/quintal)			
Year IV -No of harvests (month) -Quantity(green/air dry) (kg/quintal)			
Year V -No of harvests (month) -Quantity(green/air dry) (kg/quintal)			
Expected yield *Percentage of expected yield*			
Thinning/Pruning period (year) -First -Second -Third -Fourth			
Woody residue collected (green/air dry) unit (kgs/quintal) -First -Second -Third -Fourth			
Usage of woody residue			

V. Marketing details

Time of harvest	Year I	Year II	Year III	Year IV	Year V
Final product: Fruit, seed, oil or biodiesel. - If oil or biodiesel:					
- Total cost of processing					
- Percentage used locally					
- Local usage of product					
- Use of byproducts					
Nearest market for product -Name -Distance					
Means of transport					
Cost of transportation (Rs)					
Any MOU or contract for purchase (explain) -Agent/company/processing unit -Main agreements					
Price obtained per unit quantity (Rs./ton or kg)					

V. Concluding questions

What are the biggest advantages from the Jatropha cultivation for you, your family or your village?

1. …………………………………………………………………………………………......

2. ………………………………………………………………………………………..

3. ………………………………………………………………………………………..

Employment

Increased income

Use of wasteland

Increased energy supply

What are the biggest disadvantages from the Jatropha cultivation for you, your family or your village?

1. …………………………………………………………………………………………......

2. ………………………………………………………………………………………..

3. ………………………………………………………………………………………..

Lowered income	**Low yield**
Competition with food production	**Low profit**
Reduction of community land	**Low price**
Dependence on one crop	**Pests**
Spread of pests to other crops	**No market**

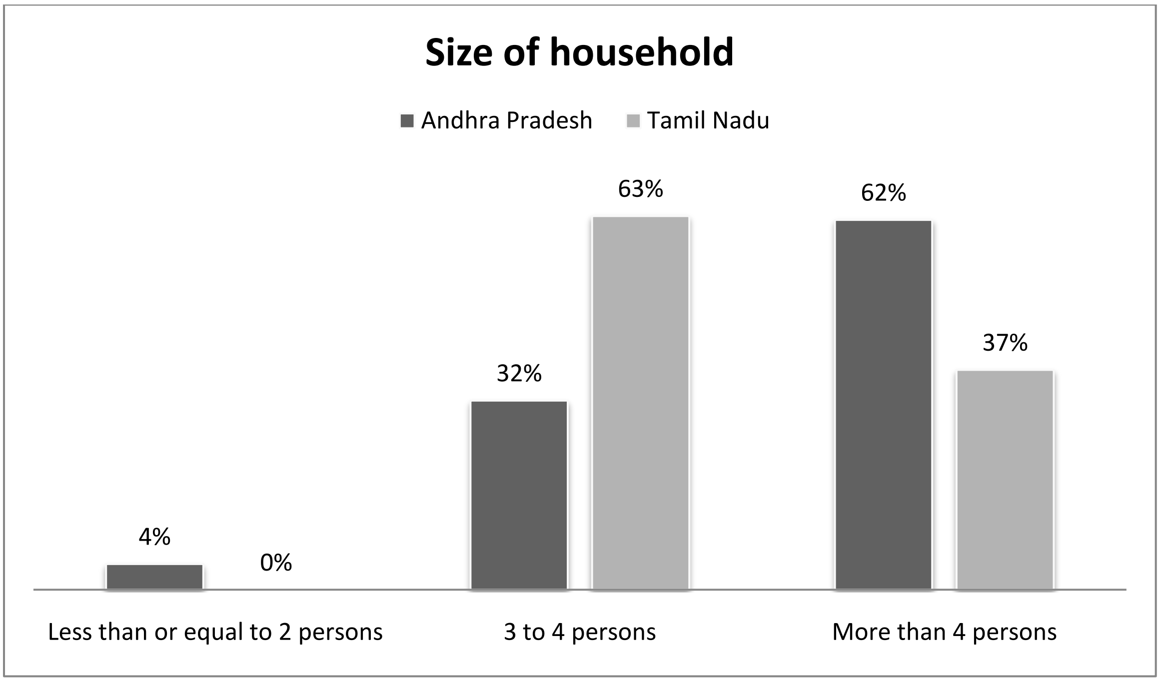
FORMAT FOR JATROPHA PLANTATION ON PUBLIC /VILLAGE COMMONS/ FOREST DEPARTMENT/INDUSTRY LAND

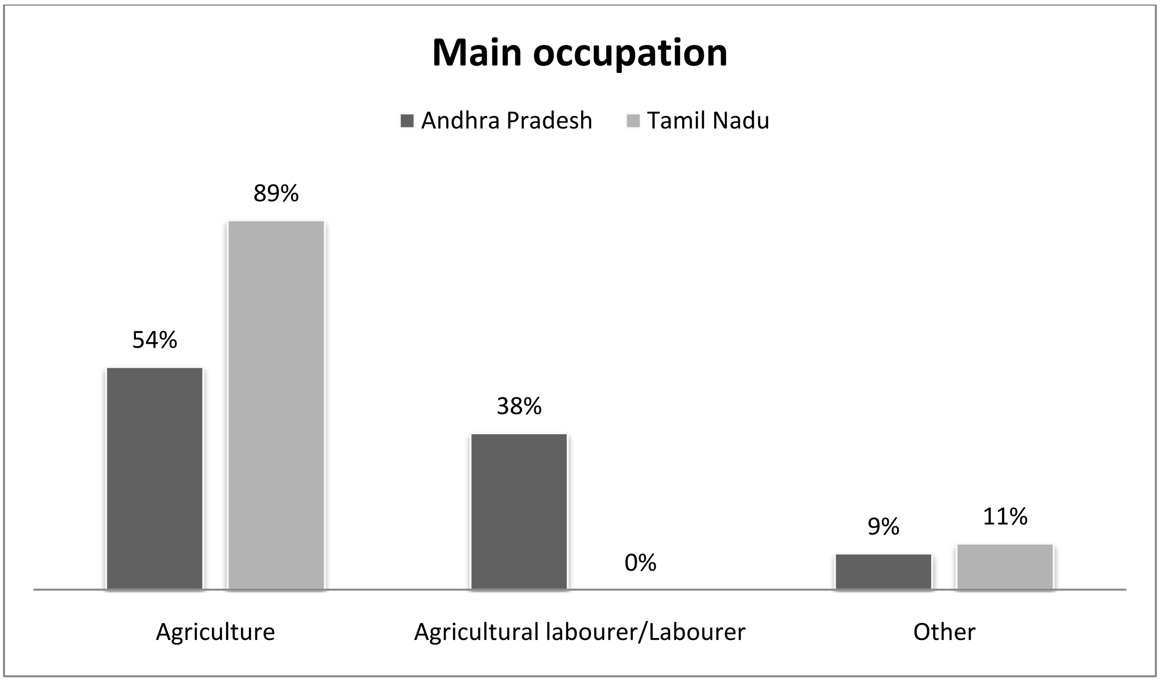
Date:

Participated in earlier study: YES / NO
Still growing Jatropha: YES / NO

Name of village	
Block & District	
Land category (tick the appropriate)	Degraded forest land / Village commons / Industry land / Others (specify)
Total area (acres)	
Area currently under Jatropha plantation (acres)	
Year of plantation	**Area proposed for planting Jatropha (in acres)**
Year I: Year II: Year III	
Any lease or agreement on and currently with Jatropha plantation	
Uses of Land under Jatropha plantation / Extent of dependence	
-No. or % of animals grazed -Period of grazing	
Fuelwood collection - No. or % of households gathering fuelwood -Type of wood collected(dry/green)	
Any management system for land	

Appendix IV. Background information on private farmers

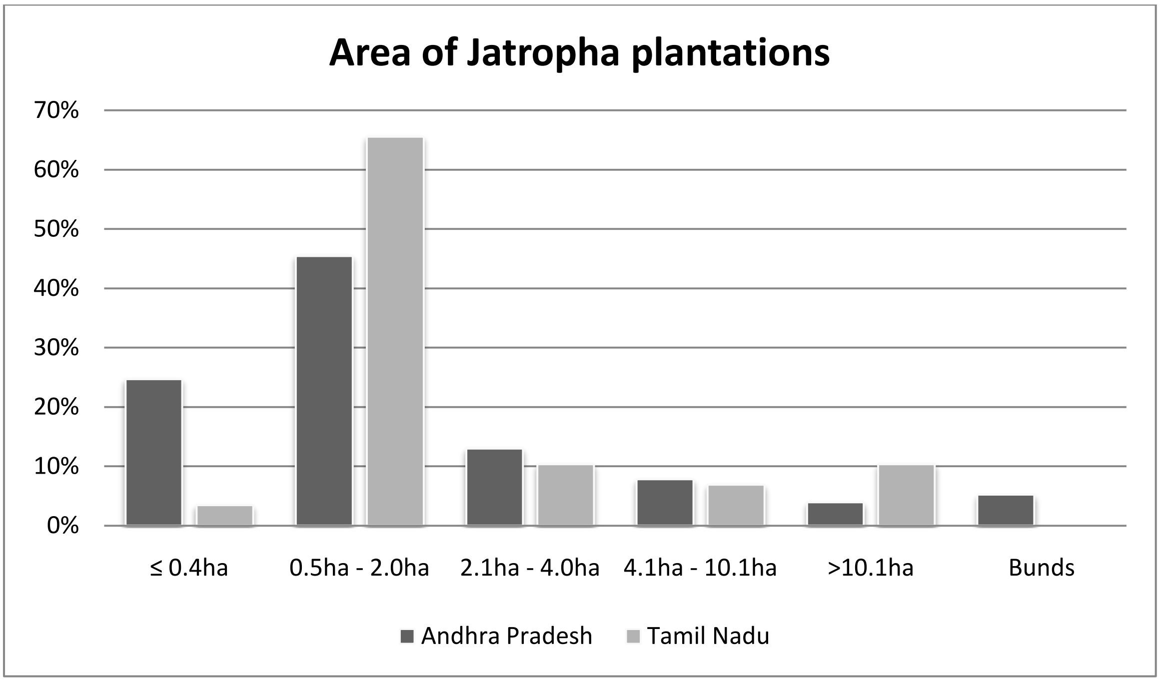




Appendix V. Categorisation of motivational factors

Category of motivational factors	Motivational factor	Criteria
Economic	Income	Returns on harvest or salary
	Subsidised agricultural facilities	Subsidies for agricultural facilities such as irrigation, or other support not mentioned as directly financial
	Financial subsidies	Directly financial subsidies given as a factor of plantation size or as a lump sum
	Loans	Access to bank loans enabled by government or private agency guarantee to the bank
Ecological	Use of wasteland	Possibility to use land that is not used for or suitable for other crops
	Jatropha characteristics	The suitability of Jatropha's characteristics; drought and pest tolerance, small demand for inputs, etc.
Environmental	Pollution reduction	The idea that use of biodiesel can lead pollution reduction
	Renewable energy	Interest in renewable energy sources
	Environmental interest	The respondents regard themselves as environmentalists, or persons with a general environmental interest
Socio-economic development	Watershed scheme	Jatropha has been planted on community land under the watershed scheme
	Energy supply	Increase in local energy supply
	Job opportunities	Creation of job opportunities for people in the village or in the local area
Other	Demonstration	Demonstration of Jatropha's suitability in order to increase the number of cultivators
	Research	Research on Jatropha's characteristics and maintenance techniques
	Government initiation	The respondent has started because he/she was "told to do so" by government actors

Appendix VI. Area of Jatropha plantations



Appendix VII. Categorisation of drivers

Category of drivers	Drivers	Criteria for driver
Economic	Future income possibilities	Expectations on future economic yield and incomes from Jatropha plantations
Ecological	Survives without maintenance	The plantations have survived without maintenance and are even yielding in some cases
	Effect on other plants	Positive effects on other plants when intercropping
Implementation	Demonstration	Demonstration of the performance of Jatropha

Appendix VIII. Categorisation of barriers

Category of barriers	Barriers	Criteria for barriers
Economic	Financial loss	Significant loss of money
	Income	No or insufficient income from the plantation
	Labour problem	Problem to acquire labour at a reasonable price
	Maintenance costs	Too high maintenance costs
Ecological	Cattle	Plantations destroyed by cattle invasion
	Flooding	Plantations destroyed by floods
	Jatropha characteristics	Jatropha's characteristics did not live up to the high expectations or realization that other crops perform better
	Pests/diseases	Plantations affected by pests or diseases
	Unsuitable land	Unsuitable soil for Jatropha cultivation
	Water scarcity and climate	Overrating of Jatropha's drought tolerance. Due to natural water scarcity and/or lack of irrigation the plants have dried or given insufficient yield
	Yield	No or insufficient yield
Market	No market	No available market for the harvest
Knowledge	Maintenance and use	Insufficient knowledge of plantation maintenance and usage of Jatropha
	Market	Insufficient knowledge about available market
	No interest	Lack of interest for continuation of cultivation
Implementation	By order	Orders from authorities
	No support	No support from the government or other initiator to maintain the plantations (financial or information)
	Unfulfilled promises	Promises made by initiators or other actors in the initial stages of plantation have not been kept