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Impacts of Jatropha-based biodiesel production on above and below-ground carbon stocks: A case study from Mozambique

Laura Vang Rasmussen [a,*], Kjeld Rasmussen [a], Thilde Bech Bruun [b]

[a] Department of Geography and Geology, University of Copenhagen, Øster Voldgade 10, 1350 Copenhagen K, Denmark
[b] Department of Plant and Environmental Science, University of Copenhagen, Thorvaldsensvej 40, 1871 Frederiksberg C, Denmark

HIGHLIGHTS

- ► Demands for biofuels make production of Jatropha-based biodiesel a priority.
- ► Farmers in Northern Mozambique are likely to convert un-logged miombo to Jatropha.
- ► Converting miombo to Jatropha creates reductions in above and below-ground carbon.
- ► It takes 187–966 years to repay emissions from above and below-ground carbon stocks.

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ABSTRACT

The need to mitigate climate change makes production of liquid biofuels a high priority. Substituting fossil fuels by biodiesel produced from *Jatropha curcas* has gained widespread attention as Jatropha cultivation is claimed to offer green house gas emission reductions. Farmers respond worldwide to this increasing demand by converting forests into Jatropha, but whether Jatropha-based biodiesel offers carbon savings depends on the carbon emissions that occur when land use is changed to Jatropha. This paper provides an impact assessment of a small-scale Jatropha project in Cabo Delgado, Mozambique. The paper outlines the estimated impacts on above and below-ground carbon stocks when land use is changed to increase Jatropha production. The results show that expansion of Jatropha production will most likely lead to the conversion of miombo forest areas to Jatropha, which implies a reduction in above and below-ground carbon stocks. The carbon debts created by the land use change can be repaid by replacing fossil fuels with Jatropha-based biodiesel. A repayment time of almost two centuries is found with optimistic estimates of the carbon debt, while the use of pessimistic values results in a repayment time that approaches the millennium.

1. Introduction

The global demand for alternatives to fossil fuels, especially for the transport sector, has been rapidly increasing. This has caused growth in the production of liquid biofuels, both in terms of bioethanol and biodiesel (Sorda et al., 2010). The demand is driven by the increase in oil prices, peaking at 145 US$ per barrel in 2008, and by the concern for energy supply security. In this context, the interest in biodiesel production from *J. curcas* (Jatropha) is rapidly growing as the oil produced from Jatropha is easily converted to biodiesel that meets the American and European standards (Tiwari et al., 2007). Jatropha belongs to the family of Euphorbiaceae and is a low growing, vigorous, drought-resistant tree, native to South America (Katembo and Gray, 2007). The leaves and stems are toxic to animals which prevents it from being browsed. As a result of the growing interest in biodiesel from Jatropha, agricultural land use is changing fast. Land use changes caused by biofuel production involve both a shift in crops within the presently cultivated areas and an expansion of agriculture into other land use categories (Searchinger et al., 2008). The biodiesel produced from Jatropha may be assumed to replace fossil energy in the energy system, and thus it has a potential to reduce net CO_2-emissions to the atmosphere. In contrast to certain other biofuel productions, the cultivation of Jatropha usually consumes relatively little energy (Francis et al., 2005), adding to its usefulness as a means of reducing Green House Gas (GHG) emissions (Robert et al., 2009). However, the conversion from other land cover types to Jatropha may imply a change, positive or negative, in the carbon pools of vegetation and soil (Fargione et al., 2008; IPCC, 2006). To generate

* Corresponding author. Tel.: +45 32 32 25 17; fax: +45 35 32 25 01.
E-mail address: lr@geo.ku.dk (L. Vang Rasmussen).

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a net GHG benefit, the reduced emissions caused by replacing fossil fuels with biodiesel should (over a given period) balance any loss of carbon from the vegetation and soil pools caused by the change in land use associated with increasing the Jatropha area. The impacts on GHG emissions and carbon pools have not yet been measured for Jatropha (Fischer et al., 2009) and the IPCC (2006) report states that reliable estimates should be obtained by taking site specific measurements. However, the Clean Development Mechanism (CDM) of the Kyoto Protocol implies that Jatropha production may be considered eligible as a means of generating 'carbon credits'. This will require that precise information on the impacts of Jatropha production on GHG emissions and carbon pools is available (Kanninen et al., 2007; Rao, 2006). Moreover, the upcoming REDD system (Reduced Emissions from Deforestation and Degradation) implies that avoidance of forest clearing for Jatropha cultivation may justify REDD funding.

Jatropha is a multipurpose tree as it can be used both as a live fence and as a commercial crop, producing oil useful both directly as a biofuel and as a basis for biodiesel and soap (Achten et al., 2007). It can grow under a wide range of environmental conditions. It is for example often claimed that Jatropha can grow in areas with annual precipitation as low as 250 mm (Foidl et al., 1996; Ogunwole et al., 2008), and that Jatropha is well adapted to marginal soils although the productivity is higher on more fertile soils (Jingura et al., 2011; Valdes-Rodriguez et al., 2011). These properties have made Jatropha a focus for NGOs, private-sector companies and local communities in many parts of the world (Dyer et al., 2012).

This paper reports the results of a study of a small-scale Jatropha production project initiated by an international NGO, FACT-Foundation (Fuels from Agriculture in Communal Technology), with the purpose of promoting local rural development in the Cabo Delgado Province of Mozambique. The specific aim of this study is to estimate the impacts on above and below-ground carbon stocks following a land use change to increasing Jatropha production for biodiesel. This involves answering the following questions:

1) What are the likely short, medium and long term land use changes caused by increased Jatropha production?
2) What are the net impacts on CO_2-emissions and carbon pools in vegetation and soil of growing Jatropha on land presently occupied by maize and forest?

2. The study area and the agricultural system

2.1. Geographic settings

The study area is located within the northern parts of Mozambique in the Cabo Delgado Province. The study was carried out in five districts (Macomia, Ancuabe, Quissanga, Meluco and Metuge). The population density is 18 inhabitants per km^2, slightly lower than the national average. Annual rainfall averages 850 mm year^{-1}, 92% of which falls between November and April (Mozambique Central water Board, 2005). The average annual air temperature is 27 °C. The soils of the study have developed on calcareous sediments and have been classified as Vertisols (Gouveia et al., 1972).

2.2. The forest areas

The natural vegetation in the study area is miombo woodland, dominated by *Brachystegia longifolia, Acacia polycantha, Pterocarpos angolenses* and *Cordila Africana.* Miombo woodlands comprise trees reaching 10–20 m in height and a single storey which can be partly closed. There is a discontinuous understorey of shrubs, and a sparse but continuous layer of herbaceous vegetation (Nhantumbo et al., 2001). The miombo woodlands in the case area consist mainly of un-logged forest, dominated by large trees. The area is classified as a 'national park' and is under State ownership. This does not imply that cultivation is prohibited as the land is co-managed by various stakeholders including government institutions, non-governmental organisations, local communities and to some extent the private sector. However, intense resource extractions must be approved by the government.

2.3. Cultivation of maize

The agricultural use of the area may be characterised as shifting cultivation or short fallow rotation with five years of cropping and five to seven years of fallow. The shifting cultivation plots average about 1 ha, but range from 0.5 to 12 ha. There is no use of manure, mineral fertilizers or pesticides. Maize is the most important crop and yields average 693 kg ha^{-1} year^{-1}. Maize prices (2–5 MZN kg^{-1} which equals 0.08–0.2 US$ kg^{-1}) in the region are presently well below the world market prices (reached 0.28 US$ kg^{-1}in 2008 (FAO, 2009), which equals 7 MZN).

2.4. Cultivation of Jatropha

Jatropha is planted as hedgerows around the shifting cultivation plots in the study area. At the onset of the rains Jatropha is planted as seedlings in holes filled with a mixture of local soil and compost. There is no use of manure, mineral fertilizers or pesticides. The ages of the Jatropha trees range from one month to two years. Due to the novelty of the production the mean yield was 0.4 kg tree^{-1}, but ranged from 0.1 kg to 1 kg. However, as the yield is expected to increase over time up to an age of about 6–10 years (Achten et al., 2008), the measured yields in the study area are not representative for mature Jatropha trees.

The Jatropha hedgerows may best be described by their length and by the average distance between trees in the rows. In order to produce yield estimates and changes in carbon pools, these characteristics must be converted into an area-based measure (number of trees ha^{-1}). The mean spacing between the trees in the study area is 100 cm. As the field sizes average 1 ha and are approximately quadrilateral, the average perimeter is in the order of 400 m. Farmers make a ditch with a width of about 3 m around their fields before planting Jatropha. With a spacing of 1 m, a hedgerow around a field of 1 ha will thus average 400 trees and take up 1200 m^2, which corresponds to 3333 trees ha^{-1}. This corresponds to the recommended number of trees per hectare ranging from 1100 to 3300 (Openshaw, 2000).

Planting Jatropha with a typical lifecycle of 20 years as hedges around plots which are cultivated for five years may appear contradictory. The investment in hedge planting may thus indicate a movement towards more permanently cultivated fields. Continuous maize cultivation may require application of fertilizers, which in turn would demand that an income is generated. Such changes cannot be detected yet, since planting only started a couple of years ago.

The agricultural system may be seen as almost exclusively subsistence oriented and commercial farming systems are virtually absent in the project area, yet basic commodities such as maize are marketed locally. Jatropha may be seen as the first (potentially) commercial crop introduced.