MANUSCRIPT COVER PAGE

This manuscript is in preparation. Please do not refer to this paper without written permission by the corresponding author indicated on this cover page.

Status: In preparation

Date: 2009-10-19

Format:

Journal: Book Chapter in *Jatropha curcas* as a Premier Biofuel: Cost, Growing and Management

Category: Commentary/Short Communication; <4000 words

Work title: *Jatropha* integrated agroforestry systems – biodiesel pathways towards sustainable rural development

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Words: 3690 (including in-text citations)
Figures: 1
References: 56

Title

Jatropha integrated agroforestry systems – biodiesel pathways towards sustainable rural development

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Abstract

The current "*Jatropha* hype" attracts large-scale investments in the cultivation of *Jatropha curcas.* This will mainly result in an expansion of large-scale monoculture plantations of the species. Ironically, the problems associated with such monocultures – problems of economic, social and environmental sustainability, along with pests, diseases and potential hydrological consequences – threaten to dim the interest in the species. Therefore, alternative cultivation systems should be explored. *Jatropha* has potential to be integrated in diverse agroforestry systems, which in general offer better guarantees to become sustainable, as they aim at combining socio-economically viable production with environmental conservation. In this chapter, the different options to include *Jatropha* in agroforestry systems are described (*e.g.*, boundary plantings, contour hedges, live fences, windbreaks, hedgerow intercropping, parkland and silvopastoral systems). Their potential social, economic and environmental risks and benefits are discussed. In particular land use changes related to *Jatropha* cultivation, their possible impact on food supplies and the up-scaling possibilities are focused upon. Based on this assessment, we provide clear guidelines for the expansion of *Jatropha* cultivation on a sound socio-economic and environmental basis.

Keywords: boundary planting, contour plantings, intercropping, *Jatropha curcas*, live fences, silvopastoral, smallholder, small scale, windbreak

1. Introduction

Currently, there is a global and sharply increasing interest in biofuels in the public, politic and scientific domain. This booming interest is mainly driven by the global quest for CO_2 emission reduction and by geopolitical issues, such as reducing nations' dependency on (foreign) fossil fuel [1], and has lead to directives, blending targets and national biofuel missions worldwide [2,3]. As an example, the target of the European Energy and Climate Change Policy is to cover 10% of the European transport fuel demand with biofuels by 2020 [2] and recently the Biofuels Research Advisory Council reported that a biofuel coverage of 25% of the EU road transport fuel by 2030 is realistic [4]. However, the criticism about biofuel use has grown along with the global interest in it. Several reports describe economic (*e.g.*, subsidies, protectionism), social (*e.g.*, food security, labor conditions) and environmental risks (*e.g.*, loss of biodiversity, hydrologic control, negative carbon balance) involved with large-scale use of biofuels [5-10].

In this debate, biofuel from *Jatropha curcas* could be a promising alternative, as this crop is expected not to compete with food production [11] and/or to deplete natural carbon stocks and biodiversity. These expectations are mostly based on non peer-reviewed reports describing the drought tolerance of the species, the yield potential (0.4- 12 t dry seed ha^{-1}), the low need of nutrients and water (from average annual rainfall of 200 mm), the toxicity of the oil and the low vulnerability to pests and diseases [12]. The possibilities to simultaneously reclaim wastelands, provide fuel and have a positive effects on the socio-economic development in degraded areas have provided *Jatropha* the status of 'miracle tree' [13] and is attracting major investments. However, these investments will primarily result in a global expansion of monoculture plantations. In 2008 commercial (>5ha) and large scale plantations (>1000ha) took 20% of the total area planted with *Jatropha* (936,000 ha) [14]. By 2013 this share would be 43% [14]. Considering an anticipated area of 4,720,000 ha by 2010 and 12,800,000 ha by 2015 [14] and with the current state of knowledge [11,15] this expansion holds risks of unsustainable practices [16].

2. Sustainability risks

Major knowledge gaps on *J. curcas* genetics, agronomy and land suitability result in high performance uncertainty and host the biggest risk for monoculture expansion [11,15]. The intraspecific genetic diversity has only marginally been studied (*e.g.,* [17-19]) and plant growth characteristics related to seed and oil yields are only just being identified [20,21]. Although breeding programs and systematic selection are ongoing, *Jatropha* is yet to be domesticated and should still be considered as a wild or at best semi-domesticated plant [11,15].

No allometric relations, no input-response functions, neither for physical and chemical inputs, nor for management inputs, and no clear insight in necessary biophysical conditions are available [15]. Consequently, yield is difficult to predict [11]. Furthermore, large *Jatropha* monocultures are likely to be more susceptible to pest and diseases [22,23]. Additionally, potential environmental impacts of the large-scale cultivation of *Jatropha*, such as its impact on water resources and hydrological balance, are unknown [11,24] and the economic viability of such initiatives is unsure, certainly if potential social and environmental costs are accounted for [16]. This highly uncertain perspective, together with competition on the global biofuel market, raises the concern that *Jatropha* investors might be further drifted away from the marginal or degraded lands towards agricultural or natural valuable grounds, in order to reduce yield uncertainty and financial risk. In such a situation, *Jatropha* will loose its acclaimed sustainability advantages compared to other biofuel crops. Unsatisfying results or unexpected impacts of large-scale plantations might dim the enthusiasm for the species as a whole, despite the fact that these impacts are likely to be avoided when the species is cultivated in smaller-scale agroforestry systems [25,26].

We argue that: (*i*) integrating *Jatropha* cultivation into a properly designed agroforestry system can reduce social, economic and environmental risks and conflicts of *Jatropha* biodiesel production, and that (*ii*) *Jatropha*-integrated smallholder production systems can form a robust base to implement the beneficial attributes of agroforestry.

3. Potential Agroforestry Niches

3.1. General

The World Agroforestry Centre (ICRAF) defines agroforestry as a collective name for land-use systems and technologies, where woody perennials are deliberately used on the same land unit as agricultural crops and/or animals, either in some form of spatial arrangement or temporal sequence [27]. In agroforestry systems there are both ecological and economic interactions between the different components.

Agroforestry systems deliver several ecosystem services at local scale, including microclimate modification, erosion control, mitigation of desertification, carbon sequestration and pest control, and supportive services, i.e., soil fertility improvement, biodiversity conservation and pollination [28]. In addition, at larger scale, they help in mitigating land degradation, climate change and desertification [28]. Where agroforestry is applied to restore degraded lands, it also is likely to provide tree-based goods and services while keeping the land in agricultural production. Such agroforestry can also be used to link forest fragments and other critical habitats as part of a broad landscape management strategy that enables species to be conserved while adding structural and functional diversity to the agricultural landscapes.

3.2. Basic agroforestry systems

In what follows, some definitions on agroforestry systems are given as stated by the World Agroforestry Centre [27]. There are two basic categories of agroforestry systems: simultaneous (trees and crops or animals at the same time on the same piece of land) and sequential (crops and trees take turns in occupying the same space). Here, an overview of the simultaneous systems is given. Many simultaneous systems are linear arrangements (rows or strips): (i) Boundary plantings are trees used to delineate plots of farms. Additional the trees can provide wood or other products. (ii) Contour hedges are planted to prevent erosion and to form biological terraces. (iii) Living hedges, live fences and woody strips are all variations on the technique of using shrubs or bushes to form a continuous barrier. They are used to form animal paddocks (or conversely, to keep animals out) and can provide wood and other products as well. (iv) Windbreaks or shelterbelts are used to protect crops or animals. These techniques conserve soil moisture, give shelter to the farm home and diversify the landscape as well. (v) In hedgerow intercropping or alley cropping trees are planted on land along with crops; the crops are grown in alleys between the rows of trees. The aim is to maintain or improve soil quality. However, because of competition between hedge and crop for moisture and nutrients, alley cropping has proved practical only in limited circumstances (vi) Parkland systems include combinations of trees and crops in which the woody component is a permanent upperstory. However, the tree cover can be quite open or totally closed dependent on the understory crop. Multipurpose trees may be scattered on the cropland. (vii) Silvopastoral systems incorporate discontinuous tree story over a continuous grass cover. The animals can graze in pastureland under trees.

3.3. Agroforestry options for *Jatropha* production

Jatropha has been used in linear arrangements for decades [25]. At a spacing of 15-25 cm within the row and between different rows, 4000-6700 plants can be planted per kilometer [15], however wider spacing is possible.

Such plantings are suitable for several of the above-mentioned agroforestry systems, such as boundary plantings on the bunds of farm plots, but can also be planted on ‘lost strips of land’ along rail and highways. However, *Jatropha* has specific characteristics which make it suitable for more multifunctional agroforestry options.

Gübitz *et al.* [29] mention that the use of linear *Jatropha* arrangements can control and prevent soil erosion. Although more research on that perspective is needed, observations on the root structure, which is remarkably persistent and symmetric, confirm *Jatropha*’s potential to control soil erosion by wind and water [30]. The lateral roots decrease soil erodibility through additional soil cohesion, while the taproot and sinkers may enable stabilization of subsurface soil [30]. As such *Jatropha* can be used for contour hedges as well. Additionally, due to the stabilizing capacity, *Jatropha* can also be used to stabilize riparian zones or irrigation canals.

Jatropha contains toxic properties preventing it from getting browsed by cattle and roaming animals. This characteristic makes the species useful as living hedge or live fence plant, similar to *Euphorbia* hedges widely used in the tropics. *Jatropha* fences can enclose farm animals (paddock), or exclude animals to protect food crops (*e.g.*, rice, cereals, horticultural crops). In the latter case *Jatropha* both fulfills the boundary and the protection function. Similarly *Jatropha* rows can serve as windbreaks or shelterbelts to protect crops or animals from climatic instances as well (*e.g.*, protecting Banana from hot winds in Allahabad, India [31]). Due to the high water content of the twigs, trunks and leaves [24] *Jatropha* has been planted as fire barrier in China as well [32].

Jatropha also hosts opportunities for integration in hedgerow intercropping and alley cropping systems. *Jatropha* improves the soil quality [33], particularly in degraded conditions [34]. Furthermore, recent insights in the plant water relations of the species point has a conservative water use strategy [24], limiting the competition for water. However, further investigation is needed for both aspects, as well as the competition for nutrients and light, as they are still poorly developed for the species in general and for its application in intercropping systems in particular (van Noordwijk *et al.* 2007 http://tinyurl.com/lgj329). In India, several intercropping systems are proposed and tested where *Jatropha* was intercropped with *Linum usitatissimum* (Linseed), *Vigna unguiculata* (Cowpea), *Zingiber officinale* (Ginger), *Solanum lycopersicum* (Tomato), *Psidium* sp. (Guava) and *Aloe vera* [33,35,36]. Although current insight in the intercropping potential of *Jatropha* is sparse, early predictions of the intercropping potential of *Jatropha* in Indonesia, using a tree-soil-crop interaction model (WaNuLCAS), show interesting opportunities for a sustainable agroforestry system with *Jatropha*, food crops (*e.g.*, Cassava and Groundnut) and timber trees (Mahogany) (van Noordwijk *et al.* 2007 http://tinyurl.com/lgj329). Sahoo *et al.* [33] report on successful intercropping in India with *Moringa oleifera, Leucaena leucocephala, Pongamia pinnata, Acacia* sp. and *Azadirachta indica*.

Integration of *Jatropha* in a parkland system had been proposed by Lengkeek [37], in which the species can be either systematically spaced (*e.g.*, 2×2 or 3×3 m), randomly sown or mixed with other species. The open or closed character of the canopy will determine the crops growing underneath. Concerning interactions, the same problems are faced as for the intercropping hedgerows.

Although there are many options to integrate *Jatropha* in agroforestry systems, currently the integration of *Jatropha* as boundary plantings, contour hedges, living hedges and windbreaks in agricultural landscapes is expected to suit any kind of agricultural system and is seen as the cheapest option with the least risk to farmers.

3.4. Smallholder opportunities through *Jatropha* production

The main rationale for integration of *Jatropha* in agroforestry systems is the combination of the *Jatropha* agroforestry functions (*e.g.*, boundary, protection, erosion control) with the production of oil, which would provide an additional income and induce risk spreading through income diversification for the adopting farmers. After harvesting the fruits (seed and hull), the seeds have to be separated from the hull. The oil is easily extractable from the seeds with simple and cheap technology [15,38], and is suitable for use in lamps, stoves and static running engines (*e.g.*, mills, tractors, generators) [15]. The oil can be used as substitute for fossil fuel in land-locked or very remote areas, where fossil fuel supply is erratic and the prices very high. In such communities, local and relatively cheap biofuel production can enhance rural development and can alleviate the pressure on natural ecosystems. For communities having sufficient access to fossil fuels, the *Jatropha* oil can also (partly) substitute fossil fuels, reducing the communities' dependency on fossil fuel price fluctuations. A nation-wide application of *Jatropha* agroforestry systems could even reduce the nations' dependency on foreign oil import and therefore indirectly contribute to the country's development.

Besides using the oil for energy, it can also be used for soap production, a typical female activity in developing countries [38,39], enhancing gender equity. In addition, local *Jatropha* cultivation and oil extraction would provide several locally useful by-products as well, which is often not the case in centralized processing setups [13] used in large-scale projects. The pruned wood waste, the dried fruit hulls and the seed cake are useful as combustible [29] replacing fuel wood in woodlots or forests. The seed cake (the organic left over after oil extraction from the seeds) contains high levels of nutrients and proteins [15] and is valuable as fertilizer. It can also be used as animal feed, provided that the seed cake undergoes a detoxification process. Yet this process, of which the necessary investigations are currently ongoing (*e.g.,* [40,41]) requires significant investments, hampering its viability at local scale in developing countries [13]. Likewise, local production of biogas and producer gas from seed cake and fruit hulls is possible [13,42,43], but requires local infrastructure (*e.g.*, biogas digester, gasifier).

3.5. Conditions for implementation

Implementation of this *Jatropha* agroforestry approach requires (*i*) suitable areas and suitable agricultural systems, (*ii*) extension efforts and (*iii*) farmers' willingness to adopt *Jatropha* in such systems.

3.5.1 Suitable areas

Soil conditions **-** Although *Jatropha* can grow in a wide range of soils [15], heavy clay soils should be avoided [25] and well drained and good aerated soils are preferred [25,44] as *Jatropha* cannot stand water logging [36,45]. The soil depth should exceed 45 cm [35] and surface slope should not be more than 30° [31]. Soil pH should not be higher than 9 [31,45].

Climatic conditions - A claim which added largely to the current interest in the species is the fact that *Jatropha* is said to thrive in very dry conditions (*e.g.*, [11,25,46]). Yet, this claim is backed with surprising little evidence as in its natural distribution area, the species naturally grows in tropical savannah and monsoon climates (A_m, A_w) and in temperate climates without dry season and with hot summer (C_{fa}), whereas its natural presence is very limited in semiarid climates (B_S), and even totally absent in arid climates (B_W) [47].

In its natural distribution area it rarely occurs naturally below 944 mm rainfall or below an aridity index (the ratio of mean annual precipitation to total potential evapotranspiration) of 0.55 [47]. The species can most probably grow in dryer regions, but its productivity and ecosystem function delivery will be limited. As an example, production in plantation sites with 900-1200 mm rainfall is up to twice as high (5 t dry seed ha^{-1} yr^{-1}) as in semi-arid regions (2-3 t dry seed ha^{-1} yr^{-1}) [13,15].

Use of *Jatropha* should be avoided in frost-prone regions [47]. The plant immediately sheds its leaves after mild frost events, leading to very low seed production, while more severe frost is lethal for the species [25,33].

3.5.2 Extension efforts

Extension efforts are primordial to assist in the suitability evaluation of locations and agricultural systems. Extension and dissemination of the *Jatropha* agroforestry opportunities, facilitated by cooperatives and local networks, should start with the communication of correct information on the land suitability, including potential yield range, risks of yield loss, necessary management practices and light, water and nutrient competition. These cooperatives and local networks should also be enabled to assist farmers in acquiring plant material at low cost and in the harvesting and post-harvest processing techniques and infrastructure.

3.5.3 Willingness to adopt

Finally, the *Jatropha* agroforestry approach can only be implemented if farmers are willing to adopt *Jatropha* in any of the possible systems. Farmers' adoption of technologies is generally affected by a range of factors including technology-specific factors, household-specific factors, geo-spatial factors and the institutional and policy context within which the technologies are disseminated to farmers [48]. However, the main condition for farmers' willingness to adopt is the profitability of the introduced system compared to the current farmers' activities [49].

In a switch from conventional agriculture to agroforestry, the boundary plantings, living hedges, windbreaks and hedgerow intercropping of *Jatropha* will reduce the area planted with the agricultural crops, potentially causing yield loss. In silvopastoral systems *Jatropha* might reduce the carrying capacity (i.e. the amount of animal units a land area can sustain) of the pasture land, as *Jatropha* itself is not browsed. In such a situation the return from *Jatropha* has to compensate for the loss. The multipurpose character of *Jatropha* can do this through at least two different mechanisms (or a combination of them): (*i*) by returning products (oil, seed cake, fruit hulls, pruning waste) which, by substituting current products (diesel, kerosene, fuel wood, fertilizer), have a value; and (*ii*) by increasing productivity (yield per area unit) of the agricultural crops by improving field conditions, by reducing losses through *Jatropha*'s protection function and by rising fuel availability for agricultural mechanization. Nevertheless, the economic investment should remain limited, both for planting material and for oil extraction infrastructure. As mentioned above, cooperatives and local networks are to play an important role here (*e.g.*, by making use of locally available oil extraction expertise and infrastructure or by including *Jatropha* in already existing nurseries).

3.6. Sustainability risks and benefits of agroforestry approach

In general *Jatropha* agroforestry pathways reduce several sustainability risks related to the large-scale monoculture expansion. First, the farmer can individually limit initial investment and control his/her start-up risk. Second, integrating *Jatropha* in smallholder farms reduces the risk of environmental impact on biodiversity, ecosystem functions and hydrological control compared to large-scale monocultures. Finally, the combination of food and oil production in smallholder farms reduces the risk of *Jatropha* affecting national or global food security or of triggering further deforestation. Integrating edible oil trees such as *Moringa oleifera* or *Simarouba glauca* in the overstory of a *Jatropha* agroforesty system (i.e., vertically separated from the inedible component) may even increase food security, as the edible part of the oil crop may be consumed when the demand for fuels is low or when the demand for food is high.

Besides the specific smallholder opportunities and the general sustainability benefits described earlier in this chapter, the *Jatropha* agroforestry approach holds some specific risks as well. Some reports state that *Jatropha* is an invasive species [50,51]. Although no scientific results are available on allelopathic or invasive characteristics of *Jatropha*, Sahoo *et al.* [33] estimate the chance of *Jatropha* having any allelopathic effects on natural vegetation to be remote. The seed cake, rich in nutrients, can be used as soil amendment, but also contains toxins, among which phorbol esters, toxic to animals and humans. Although it has been reported that the phorbol esters decompose completely within six days [52] there is need for precaution in its use. The possibility of edible crops taking up these phorbol esters has not been investigated. In addition, Heller [25] reports a study showing phototoxicity to tomatoes, expressed in reduced germination, after over-application (5 tha^{-1}) of seed cake. Furthermore *Jatropha* is said to transmit the Cassava superlongation disease (*Sphaceloma manihoticola*) and could be a possible host for African Cassava Mosaic Virus (until now only observed in *Jatropha multifida* L.) [25]. Both issues need further scientific investigation. Combining food crops with *Jatropha* might increase the risk of accidental intake of the toxic seeds by humans [16]. Further to the toxicity, Gressel [53] warns for a lack of information on the health effects of burning *Jatropha* in closed rooms. These two issues deserve serious attention in the extension efforts.

3.7. Up-scaling possibilities and implications

A recent report from ICRAF [54] has highlighted patterns of tree canopy cover over cropland across different climatic and demographic conditions. The zonal 80 percentile tree cover value – that is the value of tree cover found for the 80^{th} percentile observation (from low to high) from among all those in the same climatic and population density classification – is compared to existing tree canopy cover in Africa to identify agricultural areas with tree inclusion potentials, namely a potential increase in agroforestry. This agroforestry potential is more specifically an indicator of underuse of trees that is not justified either by climatic and population density pressures, which often are the factors most limiting tree inclusion. Within areas with agroforestry potentials, Figure 1 illustrates suitability levels for *Jatropha* natural occurrence and seed productivity, estimated with a bio-geographical approach, which relates presence observations with environmental conditions [55].

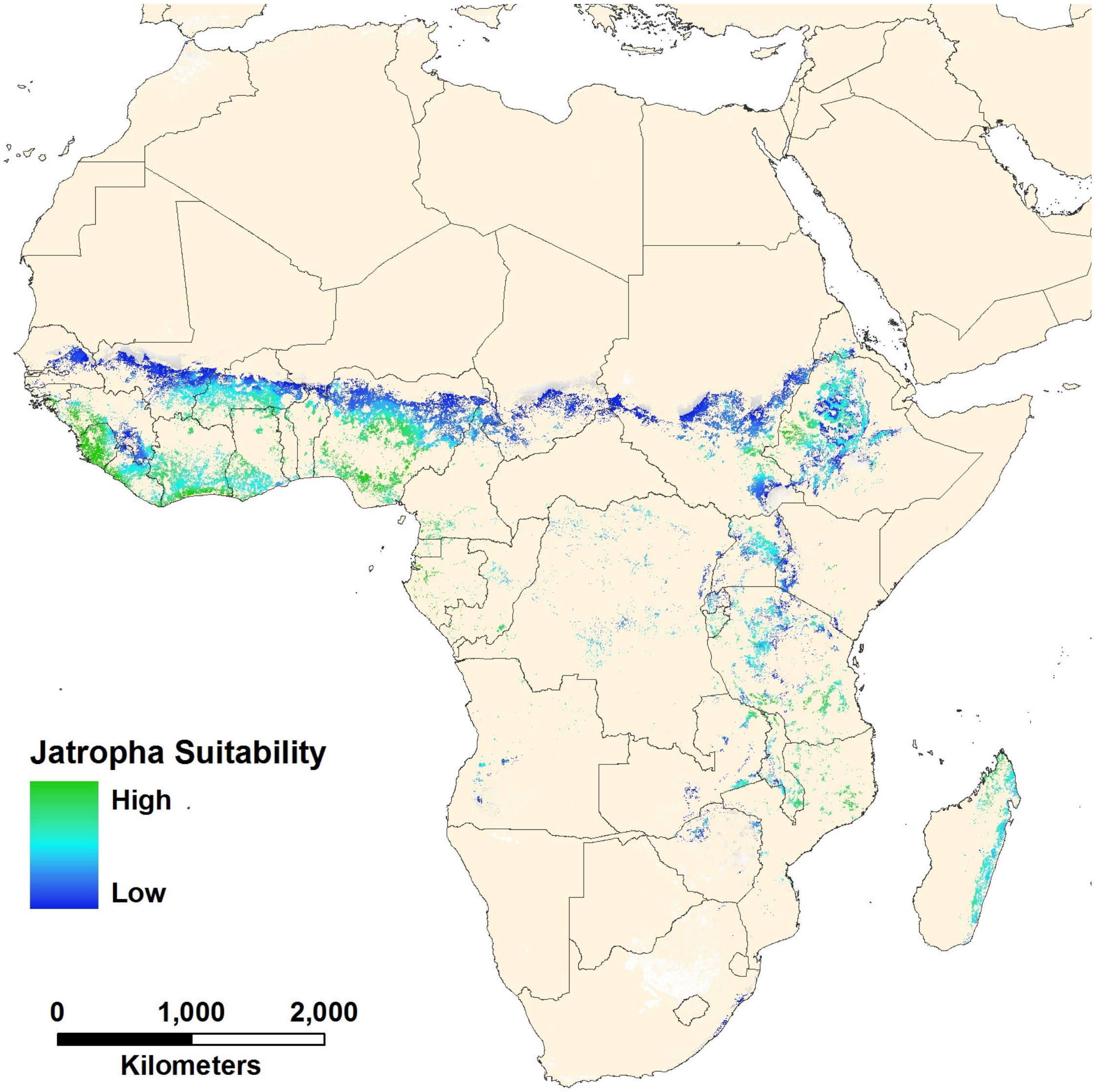

Figure 1. Map of *Jatropha* suitability levels in Africa within agricultural land with potentials for tree inclusion.

Despite the remarkable potentials of using *Jatropha* as a biofuel source, implementation in agroforestry relies on further scientific and technological support. There are several challenges for scaling up after implementation. First, the strategies required to incorporate

Jatropha into mainstream agricultural extension systems are virtually inexistent. Second, the limited capacity of extension workers in *Jatropha* might hamper the up-scaling. Third, access to quality germplasm (seed) is a major constraint to all tree-based interventions. Last, land tenure insecurity and property rights to trees may pose constraints in some areas as well. It is clear that further development of technical, political, development and policy contexts is necessary to scale up adoption of *Jatropha* integrated agroforestry initiatives.

4. Conclusion

Major drivers of low agricultural productivity in sub-Saharan Africa are land degradation, climate change and limited energy availability. *Jatropha* has provides to potential for providing rural communities with multiple bioenergy services and income sources that can improve their livelihoods. The participation of smallholders in the emerging biofuel markets could potentially contribute to increased productivity, poverty reduction and environmental sustainability. However, if *Jatropha* planting is improperly implemented, expansion of its production could result in food shortages through displacement of smallholder farmers from productive lands, and may also have a negative impact on the environment [56]. In this commentary we conclude that the research for development basis for promoting wider scaling up of *Jatropha* is still incomplete, and propose that when properly designed and strategically integrated into agroforestry practices, such as boundary plantings, contour hedges, living hedges and windbreaks, *Jatropha*-based production can contribute to income generation and ecosystem services by mitigating land degradation and desertification, and creating additional carbon sinks while adding structural and functional diversity to the agricultural landscapes.

Acknowledgements

This research is funded by the Flemish Interuniversity Council – University Development Co-operation (VLIR-UOS), K.U.Leuven FLOF and the Research Foundation - Flanders (FWO) and is a collaboration between K.U.Leuven and the World Agroforestry Centre (ICRAF).

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Figure 1