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Mini Review

A multi-factor evaluation of Jatropha as a feedstock for biofuels: the case of sub-Saharan Africa

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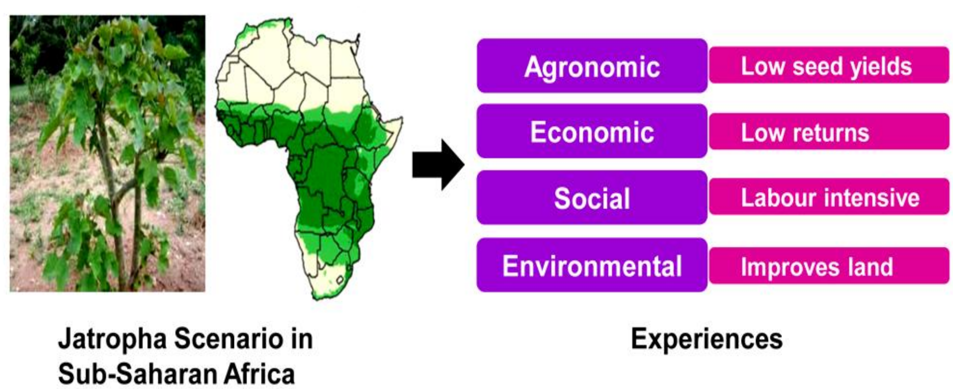
HIGHLIGHTS

- Performance of Jatropha in sub-Saharan Africa was evaluated.
- Analysis based on agronomic, economic, social, and environmental factors.
- Major challenge is low yields, usually less than 2 t/ha and poor economic returns.
- Evidences show that most of the claims about Jatropha have not been realised.

GRAPHICAL ABSTRACT



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ABSTRACT

Sub-Saharan Africa (SSA) is a geographical region consisting of 49 countries, out of which, 39 countries have experiences with the cultivation of *Jatropha curcas* L. Since the year 2000 Jatropha production escalated in the region and peaked in around 2007/2008. The major drivers of this trend were claims made about Jatropha including its ability to grow on marginal lands, high seed and oil yields, and drought tolerant, amongst other attributes. However, the reality has shown that these attributes have not been realised. The objective of the present paper is to analyse the performance of Jatropha as a biofuel feedstock in SSA based on agronomic, economic, social and environmental factors involved in its production. Evidences in SSA show that the major challenge with Jatropha cultivation has been low seed yields, ranging between 0.1 and 2 t/ha. This in turn has led to oil yields which are not sufficiently viable for use in production of biofuels such as biodiesel. There have also been reported challenges with production on wastelands, low use of inputs, unimproved planting materials and vulnerability to pests and diseases. These have negatively affected the performance of Jatropha causing the original claims made about this energy crop not materialised in the SSA.

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1. Introduction

Sub-Saharan Africa (SSA) is a geographical region covering parts of the African continent located south of the Sahara. The region consists of 49 countries, out of which, 39 countries have experiences with the cultivation of *Jatropha curcas* L. Native to Central America, yet growing widely in Africa, Jatropha has traditionally been used for many purposes in the SSA. It has been grown as a fence to prevent animals from entering reserved areas, to control erosion or to reclaim land, for soap making, as a bio-fertilizer and for medicinal and pesticidal applications. However, the emergence of biofuels in recent times as alternatives to fossil fuels and as sources of sustainable energy, has led to a search for suitable energy crops. It is within this premise that Jatropha emerged as a suitable energy crop for the SSA.

Prior to the year 2000, Jatropha was rarely considered a feedstock for biofuels in the SSA. The interest in Jatropha in the SSA escalated in the mid-2000s and peaked around 2007/2008. Literature abounds with numerous claims originally made about Jatropha as a miraculous energy crop. These claims include high seed yields, drought tolerant, low nutrients, water and management requirements, and that the plant is well adapted to grow on marginal lands (Sale and Dewes, 2009 ; Achten et al., 2010). Suffice it to say that the acclaimed attributes of Jatropha were well elucidated as the crop entered cropping systems in the SSA (Openshaw, 2000; Brittaine and Lutaladio, 2010).

It is a fact that up until the rise in popularity of Jatropha in 2000, there were few trials and little experience in the SSA in growing Jatropha as a commercial crop (Von Maltitz et al., 2014). This rapidly changed as by 2007, the Global Exchange for Social Investment (GEXSI) estimated that 119,000 ha of Jatropha had been planted in 97 projects in the SSA (Renner et al., 2008). Most of the planted areas where in Madagascar, Zambia, Tanzania and Mozambique. GEXSI's projections at that time were that more than 2.2 million hectares of Jatropha would have been planted in the SSA by 2015. The driver of this trajectory was that Jatropha would drive the liquid biofuels industry in the SSA, particularly through processing of Jatropha oil into biodiesel.

The reality, however, has shown that the scenario projected for 2015 has not been the case. Notwithstanding the claims made about Jatropha and the subsequent rise in its cultivation in the SSA, the interest in Jatropha has subsided in the last few years. Reasons for the decline can be discerned from the experiences with Jatropha cultivation accrued in the last 14 years in the SSA. In order to do this, this paper describes the claims made about Jatropha under agronomic, environmental, economic and social factors. Moreover, it further provides an analysis of the performance of Jatropha under these multiple factors. The objective of the present work is to contribute to the development of Jatropha as a feedstock for biofuels using lessons learnt from its cultivation in the SSA.

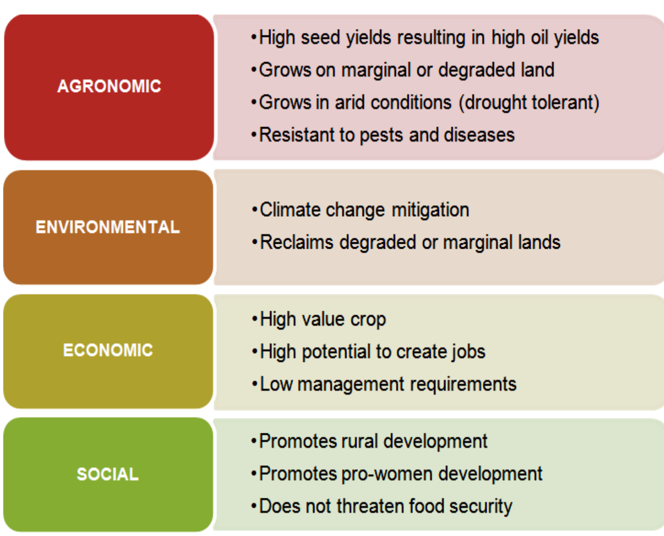

Fig.1. Claims made about Jatropha.

2. Description of claims made about Jatropha

Several claims were made about Jatropha as a suitable energy crop. It is useful to describe these claims in order to provide a comparator scenario for evaluation of Jatropha as an energy crop. The claims made about Jatropha can be placed into four categories including agronomic, economic, social and environmental factors. **Figure 1** provides an outline of the claims that were made about Jatropha in the early 2000s.

The impact of the claims shown in **Figure 1** was a massive planting programme where thousands of farmers were encouraged to plant Jatropha in many countries in the SSA. Tanzania alone had more than 10,000 smallholder farmers who established Jatropha plantations (Wahl et al., 2009). The acclaimed agronomic and economic merits of Jatropha were the major drivers for its cultivation as an energy crop in the SSA.

3. Biofuel feedstock potential of Jatropha

One acclaimed merit of Jatropha with direct relevance to its use as a feedstock for biofuels is the high seed yield potential which is correlated to high oil yield. Oil is the precursor for liquid biofuels such as biodiesel. The two main factors in any commercial crop production systems are yields and economic viability. In fact, the biggest selling point of Jatropha in the SSA was the unproven claim of high oil yields resulting from high seed yields (Pohl, 2010). Benchmark figures for seed yield indicated that with optimum annual rainfall of 900 to 1,200 mm, yields could be up to 5 t/ha (Maes et al., 2009). Other ranges of seed yield available in literature include 0.4 – 12 t/ha (Openshaw, 2000) and 0.1 – 8 t/ha (Heller, 1996).

It is worth noting that the reported yields of Jatropha were accompanied by little or no information on variables under which the yields were obtained. Such variables include genetic provenance, age of plantations, propagation method used, canopy management regime, rainfall, tree densities, soil types and soil fertility management (Brittaine and Lutaladio, 2010). These are critical information needed for proper evaluation of the reported data.

4. Desirable characteristics of Jatropha as an energy crop

The main thrust in this paper is production of liquid biofuels such as raw oil or biodiesel from Jatropha. As such, it is prudent to provide a set of desirable characteristics that would make Jatropha a good energy crop for the two liquid biofuels. Such characteristics form a framework for proper characterisation of Jatropha as an energy crop. This framework under conditions existing in the SSA is shown in **Figure 2**.

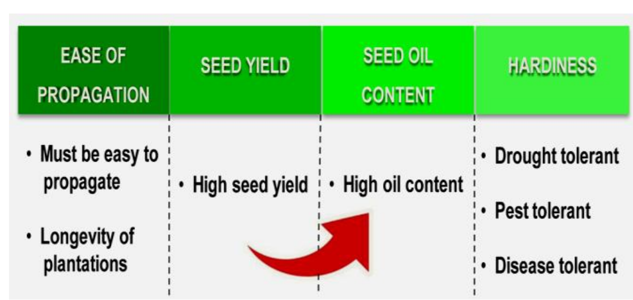

Fig.2. Framework for characterization of Jatropha as an energy crop in the SSA.

Agro-ecological zones (AEZ) in the SSA are varied. Climate adaptation is an important factor which should be taken into account when characterising crops for suitability to be grown in different areas. The dominant AEZ in the SSA are warm arid and semi-arid tropics. Diseases and pests are also problematic in the SSA and thus, the hardiness parameter in the framework shown in **Figure 2** is important in this region. The other parameters relate to agronomic issues.

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5. Factorial evaluation of the performance of Jatropha

In this section, the evaluation of the performance of Jatropha in the SSA is performed based on the four categories given in Figure 1 and the four factors given in **Figure 2**.

5.1. Ease of propagation

Ease of propagation is a parameter that falls under agronomic factors. There are generally three methods used in establishment of Jatropha plantations. These are vegetative propagation, direct seeding and transplantation of seedlings from nurseries. This provides options to farmers in establishment of plantations. Information available from GEXSI`s report shows that propagation practices varied across projects in the SSA (Renner et al., 2008). Eighty-five percent of the projects in the SSA reviewed by GEXSI were established from transplanted seedlings (Renner et al., 2008). This is not surprising as evidences from Zimbabwe showed that Jatropha established through pre-cultivated seedlings outperformed non-rooted cuttings and direct seeded plants in terms of survival (Jimu et al., 2009).

It would appear that Jatropha has been fairly easy to propagate and that the problem in the SSA has been the survival of the plants in the early post-establishment phase. In fact, there have been observations of poor early survival of plants in some plantations in the SSA. Experiences in Mozambique have shown that Jatropha required a lot of care in the first year or so of growth. Farmers in Mozambique had to provide 5 - 7 l/d water in order to ensure early survival of the plants (JA and UNAC, 2009). This makes reliance on unpredictable rainfall in the SSA problematic during the early growth phase of Jatropha. In terms of longevity, once well established Jatropha trees can survive up to 50 years. Thus, they have a long production span which leads to substantial lifetime production.

5.2. Seed and oil yields

Although seed yield is an important agronomic parameter, it is also the most economic trait for commercial production of Jatropha. It is worth noting that very little empirical data have been collected about actual seed yield of Jatropha in the SSA (Jingura, 2012). Seed yields that have been reported in the SSA are shown in **Table 1**.

Table 1.
Selected information on seed yields obtained in some Jatropha projects in the SSA.

Country	Seed yield	References
Kenya	0.1 kg seeds/tree	Iiyama et al., 2013
	0.86 t/ha	GTZ, 2009
Tanzania	1.6 t/ha	Brittaine and Lutaladio, 2010
Mozambique	> 1 kg/tree	JA and UNAC, 2009
Mali	0.63 t/ha	FACT, 2006

The data in **Table 1** serve as a reference point of actual seed yields emanating from the SSA region. Analysed against expectation, the data in **Table 1** show that Jatropha has not performed well in this region. The seed yields are far from the projected yields discussed in the Section 3. However, the figures in **Table 1** are consistent with estimates of 0 – 2.2 t/ha given for marginal lands (Ouwens, 2007). These low seed yields translate into low oil yields as well. The conversion ratio of seed to oil is about 3:1 for high efficiency systems (Pohl, 2010). Using this ratio (33% oil), oil yields from data given in Table I range from 0.2 to 0.5 t/ha. This is very low when compared to quantities obtained at seed yields of 5 to 7 t/ha which would be 1.65 to 2.31 t/ha.

Therefore, low seed yield has been the major unmet expectation from Jatropha in the SSA. According to Achten et al (2008), expectations that Jatropha would yield up to 12 t/ha were based on illegitimate extrapolations. This has mainly been from single mature trees. However, most of the data on seed yield in the SSA are from young plantations. Ages of plantation and seed yield are positively correlated. The seed yield dynamics of Jatropha in the SSA can be ascribed to various factors which are shown in **Table 2**.

Table 2.
Reasons for low seed yields of Jatropha in the SSA.

Parameter	Description
Quality of planting material	Use of wild type germplasm Absence of certified planting material
Environment	Arid and semi-arid conditions in SSA Marginal soils Prevalence of pests and diseases
Agronomic practices	Little use of fertilizers Lack of irrigation Absence of production packages

The experiences in the SSA have shown that even though Jatropha can grow on marginal lands under arid conditions, the yields are much lower than when it is grown under good conditions (Maes et al., 2009; Trabucco, 2010). The data shown in **Table 1** buttress this point. Kant and Wu (2011) provided a good explanation for this observation. They argued that the reproductive efficiency of Jatropha is dependent upon soil fertility, available moisture and temperature and these factors affect the production of seeds (Kant and Wu, 2011). The performance of Jatropha under any given conditions is largely an epigenetic response to the varied environment it encounters (Kant and Wu, 2011). Thus, the performance of Jatropha in the SSA is consistent with the production environment in the region with characteristics shown in **Table 2**.

In terms of the characterisation framework in **Figure 2**, Jatropha has not done well in terms of seed yield and this has affected the quantities of oil obtained from Jatropha plantations. However, it is reasonable to acknowledge that the low seed yields may be consistent with a crop still under domestication. However, seed yield is a trait that can be improved through breeding programmes and by crop management practices. This underpins the next phase of development of Jatropha as an energy crop.

5.3. Hardiness

One of the claimed attributes of Jatropha is the reported tolerance to pests and diseases. This would be an enormous advantage in the SSA. However, experiences in this region have shown that Jatropha is susceptible to various pests and diseases. Observations in countries like Zimbabwe, Kenya and Tanzania provide evidence of the vulnerability of Jatropha to pests and diseases. Diseases such as collar and root rot and pests such as golden flea beetle and stem borer have been reported to cause extensive damage in Jatropha plantations (FACT, 2006 ; Wahl et al., 2009).

The deleterious effects of pests and diseases in crop production are well known. Thus, an appropriate integrated pest and disease management regime for Jatropha is required to support its cultivation. As such, disease and pest tolerance cannot be excluded from breeding programmes of Jatropha.

5.4. Economic viability

The preponderance of poverty in the SSA is a major development concern. One of the major drivers of Jatropha in the region was the claim for pro-poor development leading to poverty alleviation. Jatropha was marketed as a high value crop from which large profits could be obtained (Von Maltitz et al., 2014). Without providing a detailed economic analysis, it is important to indicate how Jatropha has fared as a commercial crop.

Studies in Tanzania (Wahl et al., 2009) and Kenya (GTZ, 2009) showed that Jatropha cultivation was not a viable enterprise for the

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farmers. This is not surprising when related to seed yields given in **Table 1**. Seeds are the major saleable product from Jatropha plantations. In Tanzania, a research study showed that the net present value of a five year investment in Jatropha plantation was negative with a loss of US$65 per ha on lands with yields of 2 t/ha (Wahl et al., 2009). In Zimbabwe, and as early as 1992, a Jatropha project which was initiated by Plant Oil Producers Association was abandoned after it was realized that the profit margins were not as big as originally expected (Henning, 2003).

Reasons that can be given for the poor viability of Jatropha farming include the following:

(a) High requirement for labour
(b) High opportunity cost when grown on fertile land
(c) Low producer prices
(d) Low seed yields

The combination of these issues is a definite amalgamated factor that has caused challenges with Jatropha as a biofuel feedstock.

5.5. Social and environmental impact

High potential to create jobs is one of the claims made about Jatropha as shown in **Figure 1** under the economic factors. This is a pro-poor development strategy and would tally well with reduction of unemployment levels in the SSA. It is not surprising that as the value chain of biofuel production from Jatropha has not flourished, neither has the employment opportunities.

Ability to grow on marginal lands meant that Jatropha could be grown on wastelands, thereby limiting competition with food crops for arable lands. However, evidences in the SSA show that few plantations in the region were established on wastelands. The reality is that most of them were established on arable lands (Gasparatos et al., 2012). In such cases, Jatropha competes with food crops for production inputs. This would be at variance with the original claim of no impact on food security and labour.

One of the 12 principles of the Roundtable on Sustainable Biofuels is that biofuel production shall avoid negative impacts on biodiversity, ecosystems, and other conservation value areas (Ismail and Rossi, 2010). Jatropha has been used in rehabilitation of degraded soils, erosion control and soil improvement. Jatropha in hedge rows reduces wind erosion. The plant improves infiltration when planted in lines to form contour bunds. Thus, Jatropha has some benefits to conservation issues. However, the cumulative impact of Jatropha on the environment in the SSA remains to be seen in the long run.

6. Conclusions

The performance of Jatropha based on the multiple factors presented in this paper has been varied. Its value as an energy crop depends on the several factors highlighted in this paper. There has been no major challenge with the establishment issues, albeit concerns about survival of trees. The major issue in the SSA has been the low seed yields which have resulted in low oil yields. The production of liquid biofuels from Jatropha requires substantial amounts of oil for viability purposes. This is an issue that needs attention. It would also appear that the other claims made about Jatropha with regard to social and economic benefits have not been fully realised. In addition, although there have been indications of environmental benefits, long term impacts still need to be substantiated

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