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Analysis of the potential for sustainable, cassava-based bio-ethanol production in Mali

DANIDA contract 1711.

Feasibility of renewable energy resources in Mali

December 2012

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1. Preface

The supply of affordable, reliable and environmentally friendly energy services is an important precondition for the economic development of Malian society. Currently demand for electricity is increasing by about 10% per annum, and demand for fuel for transport is increasing at an even higher level (BAD 2010). This presents enormous challenges to the Malian government and to national operators in reducing imports of fossil fuels, as well as to the national electricity utility, EDM (Energie du Mali), and to private investors in providing sufficient electricity at reasonable prices.

A large part of electricity production comes from large-scale hydropower produced on the Senegal and Niger rivers, but small- and large-scale diesel generators are still providing about 20% of total production. While interconnectors are being planned and built to meet some of the demand with electricity produced from natural gas in Ghana and Ivory Coast, there are still good political and economic reasons to tap into abundant national renewable energy resources, such as hydro-energy, solar energy, wind energy, biomass residues from agriculture, and energy crops producing liquid biofuel.

Since the 1980s, in cooperation with various development partners, Mali has conducted a number of development projects and programmes focusing on the increased use of renewable energy sources, while the Ministry for Mines, Energy and Water has developed a strategy for the development of renewable energy in Mali, which was adopted by the Ministerial Council (Conseil des Ministres) on 26 December 2006 (MMEE 2007). This strategy combines the aims of reducing poverty, validating national energy resources and ensuring the long-term security and environmental sustainability of the energy supply. Given the rapid increase in prices for imported fuels such as diesel and gasoline, it is increasingly worthwhile to assess the potential for giving renewable energy resources a central role in the future energy system: environmentally friendly renewable energy resources are abundant in Mali and are becoming increasingly competitive.

For the purpose of planning future investment in the renewable energy sector, the Malian energy authorities, Energie du Mali, private operators and international cooperation partners have expressed their needs for a more precise assessment of the size and variety of renewable energy resources in Mali. The Danish International Development Agency (DANIDA) has therefore provided the finance to map renewable energy resources under the heading of the ‘Feasibility of Renewable Energy Resources in Mali’, or ‘Faisabilité de Resources d'Energies Renouvelables au Mali’.

A first scoping phase of the project was conducted in 2007-2008. The project report, submitted in 2008 and entitled ‘Provisional mapping of Renewable Energy Resources in Mali, or ‘Carte provisoire de ressources renouvelables du Mali’, was based entirely on satellite data and meteorological models.

The present project has taken the first study further by including ground measurements of wind and solar resources, and by including extensive field studies to assess the potential for using biomass waste for energy and to assess the socio-economic impacts of growing cassava for biofuel production. Not all renewable energy resources have been mapped, however. The most important exception is the stock of energy resources contained in Mali's woody vegetation, which is not easily assessed from satellite data but is being assessed by other on-going projects.

The present project is covered in five main reports:

1) Analyses of the potential for sustainable, cassava-based bio-ethanol production in Mali

2) Agricultural residues for energy production in Mali

3) Pre-feasibility study for an electric power plant based on rice straw

4) Estimation of wind and solar resources in Mali

5) Screening of feasible applications of wind and solar energy in Mali: Assessment using the wind and solar maps for Mali

The project is being carried out by a group of university departments, research institutions and consultants led by the UNEP Risø Centre (URC) at the Technical University of Denmark (DTU) and conducted in cooperation with Direction Nationale de l'Energie (DNE) and Centre National de l'Energie Solaire et des Energies Renouvelables (CNESOLER) in Mali. The subcontracted institutions comprise Geographic Resource Analysis & Science A/S (GRAS), Department of Geography and Geology (DGG), University of Copenhagen, Ea Energy Analyses, 3E, Ecole Nationale d'Ingénieurs Abderhamabe Baba Touré (ENI-ABT) and Mali Folkecenter Nyetaa.

2. Introduction and objectives

Component C, ”analysis of the potential for sustainable, cassava-based bio-ethanol production in Mali”, was designed to assess whether it would be economically, environmentally and socially sustainable to establish a production of bio-ethanol in Mali, based on cassava (*Manihot esculenta*). The background for posing exactly this question is (1) that Mali is in need for developing its energy supply (electricity as well as liquid fuels), (2) that it has an interest in reducing its dependence on expensive and insecure provisions of imported fuels, (3) that it has relatively large land resources available allowing expansion of agriculture, (4) that increased agricultural incomes are required to alleviate widespread rural poverty, and (5) that replacing gasoline by bio-ethanol reduces CO_2-emissions, making it interesting to Annex-1 countries to support, e.g. within the context of the ‘Clean Development Mechanism’ of the Kyoto-protocol. The reasons for investigating the potential use of cassava, rather than a range of other alternatives such as jatropha, sugar cane and sweet sorghum, as a feedstock for bio-fuel production is that (1) cassava provides comparatively good yields (up to 20 t/ha in southern Mali, considerably more than sweet sorghum), (2) it is relatively well-known to farmers, and especially smallholders, in contrast to sugar-cane, most often grown in major schemes, (3) it may be redirected to food-uses in case of a food crisis (in contrast to jatropha), and (4) it is believed to be relatively environmentally benign.

The interest in bio-ethanol from cassava is rapidly growing, as cassava is already an important crop in many farming systems in sub-Saharan Africa, as well as in other parts of the world. This is so because of its low costs and the pro-poor profile (de Vries et al., 2011) as it has been shown that typical small-holder crops such as cassava are more effective than large-scale bio-fuel production systems at raising poorer households’ incomes (Arndt et al., 2010).

In more specific terms we wish to answer the following questions, reflecting the objectives listed in the project document:

- Are there land resources available to avoid the negative impacts of competition between food production for subsistence and cassava production for bio-ethanol?

- Will large-scale production of cassava for bio-ethanol be environmentally sustainable, and will it have the intended climate change mitigation effects ?

- Is it realistic that farmers will be able and willing to increase cassava production to provide feedstock for bio-ethanol production at a price making such a production possible and profitable ?

- What will the impacts be on household incomes and equality ?

- Who are the key actors in Mali’s value chain for cassava, and what will be the effect on these actors of establishing a bio-ethanol production ?

- What will be the overall effect on food security, locally, regionally, nationally and globally, of increasing cassava production for bio-ethanol ?

- Will increased cassava production for bio-ethanol be sensitive to future climate change ?

These questions reflect the concerns often raised in relation to promoting bio-energy production in LDCs. We wish to address these concerns by seeking answers to the abovementioned questions.

The report includes findings from a case study carried out in the commune of Loulouni in the Sikasso region of southern Mali. The study area was selected because of its high potential and past history of cassava production. Findings are believed to be partly transferable to other parts of southern Mali.

3. Organization of the report

The report is organized in the following way: First we will present a brief 'systems analysis' of a facility for production of bio-ethanol, in order to guide the following analysis of its feasibility and sustainability. Next, we will report the results of the mission in November 2009, which lead to the identification of the study site. This is followed by an analysis of the likely land use implications of establishing a cassava-based bio-ethanol production in the study region, aiming at providing an answer to the third question listed above. The question of environmental sustainability is addressed in the following section, focusing mainly on the effects on the carbon stocks in vegetation and soils. Subsequently, the economic and social effects of establishing a cassava-based bio-ethanol production are analyzed, based on the household questionnaire, carried out through 2010, supplemented by interviews with individuals and groups and an analysis of the cassava value-chain. This section includes an analysis of the likely impacts on farmers' incomes and on local, regional and national food security. A brief review of what is known about the possible impacts of climate change on the cassava production follows. Finally, the conclusions are presented and policy implications discussed.

4. Systems analysis of a cassava-based bio-ethanol production facility

In order to assess the sustainability of cassava-based bio-ethanol production in the study area, a specific scale of the production must be assumed, in order to allow calculation of the necessary land use change, consequent changes in carbon pools, incomes etc. Bio-ethanol production facilities can have a wide range of sizes, yet economies of scale require an annual production of no less than 10 mill. liters of bio-ethanol (Stefan Maard, NOVOZYMES, pers. com.). Facilities are modular, implying that a facility of this size may be expanded gradually, yet with only minor reductions in marginal production costs. Due to the great volume and mass of the feedstock, transport costs of cassava will be a major factor, and thus it is likely that actual production facilities will not be much larger. Therefore we will use this size facility in our further calculations.

According to the literature the production of 1 liter of bio-ethanol requires in the order of 5-7 kg of cassava. We have no information on whether this number depends on the variant of cassava in question. Thus the production of 10 mill. liters of bio-ethanol will require 50-70.000 tons of cassava, evenly distributed over the year since fresh cassava cannot be stored for long under the conditions encountered in southern Mali. Assuming yields in the order of 10-20 tons/ha, this corresponds to a demand for land of 2.500 –

7.000 ha. Given the current intensity of land use, an increase in cultivated area of this size may be achieved within a radius of 10-20 km, which would be realistic in terms of transport. If yields were to increase, which is realistic from both an agronomic and an economic perspective, the area required would be even smaller.

In economic terms, it is evident that the precondition for a profitable bio-ethanol production is that it can compete with gasoline (since it is intended as an additive to gasoline) or with other fuels (e.g. kerosene, propane gas, fuel wood or charcoal for domestic purposes). The analysis of the production price required to live up to this precondition is difficult. Some of the problems involved are the following:

- Gasoline/oil prices have fluctuated greatly over the last years.
- Subsidies have distorted the market, sometimes to the detriment of bio-fuels.
- Lack of facilities in Mali to blend bio-ethanol and gasoline implies that adding ethanol to gasoline may only be done outside Mali, causing large extra costs of transportation.
- Internalization of environmental and social costs and benefits of the externalities of production /consumption of both bio-ethanol and gasoline and other fuels in prices would influence the result considerably.
- The extent to which CDM (or similar systems after 2012) funding can be mobilized will also impact on the analysis.
- The economic value of residues from the bio-ethanol production (which may be used as livestock fodder) is not known.

Rather than attempting to carry out a full analysis of the economics of bio-ethanol production, we will choose a realistic 'break-even price' at which bio-ethanol production will become economically feasible, and we will assume that changes in this price will be mainly controlled by changes in the oil price on the world market.

If we assume that the break-even price is in the order of 0.5 $ per liter of bio-ethanol (corresponding to a price of gasoline of approximately 0.7 $, since 1 l of gasoline may be substituted by approx. 1.4 l of bio-ethanol), the price of the raw material for the bio-ethanol production should not exceed 0.4 $ per liter of bio-ethanol, or 0.06 - 0.08 $ per kg of cassava, corresponding to 30-40 CFA/kg. This may subsequently increase when oil prices increase, as they are expected to do in the medium to long term.

In summary, we find that establishment of a production facility for bio-ethanol is likely to be feasible given that a number of pre-conditions are fulfilled. These include:

- The market (in Mali or the nearest neighboring countries) can absorb a production of 10 million liters of bio-ethanol
- A facility is located in the vicinity of a concentrated cassava production area capable of producing in the order of 50-70.000 tons/year
- In this area the production of cassava should take place in parallel with a food crop production large enough to assure food security
- The yields obtained should be a minimum of 10 tons/ha, or it should be feasible to attain this (or preferably a higher) level by greater use of inputs and agronomic expertise
- The smallholders should be willing to produce a guaranteed amount at a guaranteed price of 30-40 CFA/kg

5. Selection of the study site

5.1. Criteria

A number of criteria have been applied in the process of selecting the study site. They may be divided into three groups:

1. The availability of the basic production factors required to increase the production of cassava. These include mainly suitable land and labour resources.
2. Environmental criteria, including
    a. Suitable soil and climatic conditions
    b. Acceptable impacts of increased cassava production on ecosystems, biodiversity and water resources
    c. Acceptable impacts on carbon stocks in vegetation and crops
3. Institutional criteria (in a broad sense), including
    a. The presence and competence of local institutions, public as well as private, providing a framework for involving smallholders in the production
    b. Experience with contract farming
    c. Land rights, allowing flexible expansion of cassava production
4. Economic criteria, not the least an actual or potential price of cassava allowing economically sound bio-ethanol production
5. Infra-structural factors, including
    a. Possibilities of transporting the cassava from fields and villages to the processing site at reasonable cost
    b. Access to relevant markets, in Mali and/or neighbouring countries

In addition, the site should be selected to allow the pre-feasibility study to be carried out within the budgetary frame available.

5.2. Selection of candidate areas

The first visited is located in the Bafoulabé district of western Mali and the second includes two sub-sites in the Sikasso region in southern Mali, in Bougouni and in Loulouni commune, south of Sikasso itself. This first selection of possible sites was based on some of the criteria listed above, yet the range of selection criteria were expanded in the final selection procedure and a more rigorous procedure was applied. A third site, at Segou, was suggested but dismissed because of the lower rainfall and thus lower potential yield, in combination with its relatively high intensity of land use, causing risks of competition for land between bio-ethanol production and food production for local consumption.

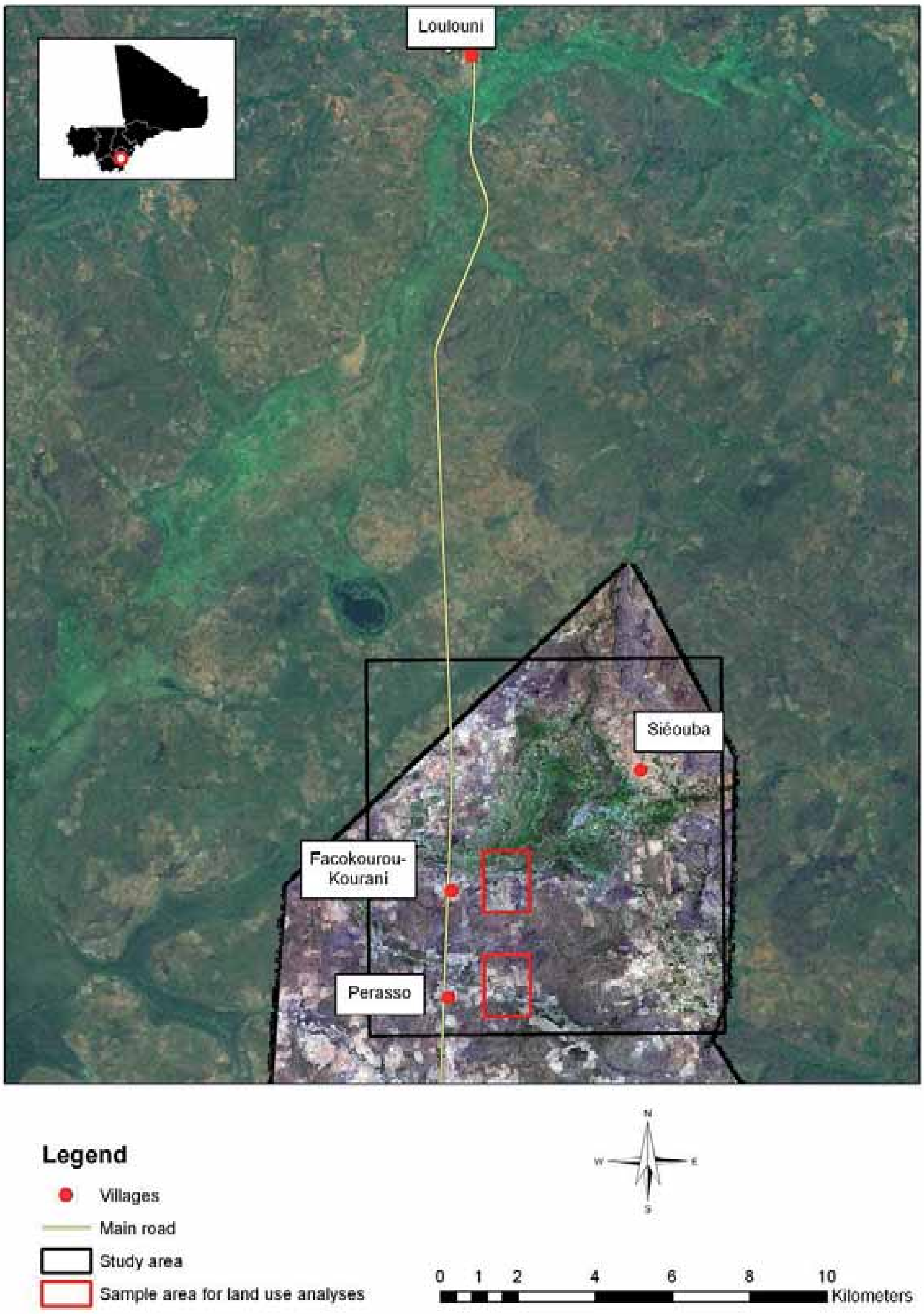


Figure 1 The study area in southern Mali

Within five days the sites were visited, and discussions were held with relevant authorities and key persons. After explaining the objective of the mission, questions were asked concerning most of the criteria listed above. The participants included political, administrative as well as technical staff at regional, district and commune levels, and in all cases the mission was provided with answers to the questions raised.

In the site south of Sikasso, time allowed visits to villages specializing in cassava production, which allowed a deeper insight into constraints on the production. During the visit to the village Sieouba, the village chairman and a number of active cassava-farmers were interviewed.

5.3. Assessment of the sites

Using the abovementioned criteria it was clear that the area south of Sikasso would be the first choice for the study: (1) The region suffers from the lack of a suitable cash crop which could replace cotton, which has been on the decrease for several years, so seen from a poverty alleviation point of view, the establishment of a stable market outlet for cassava would be much welcomed by farmers and local authorities. (2) There appeared to be sufficient land available, not the least land in fallow since cotton farming was reduced. Thus there appears to be no serious competition for land and no negative local effects on food security. This initial finding was later supported in the land use analysis, see below. (3) The carbon losses associated with land use change were expected to be relatively small, due to limited tree cover. Again this initial assumption was later tested, as reported below. (4) Farmers appeared well organized and expressed great interest in increasing cassava production, provided that a market exists and prices were reasonable and stable. (5) Farmers had considerable experience with cassava production. (6) The area was close to a major road, and the transport time to Bamako is in the order of 5 hours, making the area suitable for production for the Malian market. It is close to the borders to Burkina Faso and Côte d'Ivoire. The selected area is shown in figure 1.

The rest of this report will present material related to the selected site. The extent to which findings are transferable to other areas will be discussed when relevant.

6. Land use and production systems

As mentioned above, the implications on land use have been among the concerns in the public debate on bio-energy production in LDCs, both because of the possible environmental effects, which may offset the climate change mitigation impacts, and because of the possible negative impacts on food security in case of competition for scarce land resources between food and bio-energy production. In this section we will examine the current land use in the area and the likely consequences of establishing a cassava-based bio-ethanol production. The field work has focused on a few villages, yet the results may be extrapolated to a larger zone, required for supplying enough cassava to cover the demands of a bio-ethanol production facility producing 10 mill. liters per year.

7. Methods and data

The research reported in this paper is based on fieldwork carried out in Loulouni municipality, Kadiolo District, Sikasso Region in Southern Mali in November 2009 and February 2010. The area enabled us to study the potential for expansion of cassava production in different bio-physical environments. The fieldwork included a questionnaire survey with farmers in 2 different agro-ecological zones supplemented by interviews with key informants (farmers, farmers associations, local authorities). In total, 65 farmers were involved in the questionnaire survey which investigated issues on farming system and opportunities for cassava expansion. In addition, high resolution satellite images, a QuickBird multispectral image with approx. 2 m spatial resolution from January 2010 supplemented by older Landsat ETM images with 15 m resolution, have been used to map land use, supported by field observations.

7.1. Presentation of study area and villages

The study area is a complex landscape with large differences in soil type, topography and soil moisture conditions. Figure 2 shows the main landscape units in the case area. The classification was carried out on the basis of the QuickBird image. The following four main landscape units have been identified:

A) Flat alluvial plain: Most dryland crop production occurs in a plain situated in between the escarpment and elevated laterite plains and the low-lying seasonally flooded areas. Many fields are cultivated in a shifting cultivation system, where fields are left fallow for a few years following a crop rotation including food crops, such as maize, millet, cassava (mostly the attieké variant) and beans, and cash crops, previously cotton, now mainly groundnuts and cassava.

B) Lateritic plain/interfluves: Elevated areas, less suitable for arable production. These areas are mostly covered with shrubs and forests and are used for firewood collection and as grazing areas with scattered cultivation.

C) Escarpment /plateau: This area resembles inselbergs, with steep slopes and rocky surfaces. The plateaus are only marginally suitable for crop production.

D) Seasonally flooded area: Low-lying seasonally flooded zone, parts of which are intensively cultivated. The abundance of water allows the cultivation of several crops per year. It is cultivated with crops which respond well to abundant soil moisture, such as rice, cassava and sweet potatoes.

The areas covered by these landscape units, within the area shown in figure 2, are given in table 1

Table 1: Areas of landscape units within the study area delimited in figure 2

Land class Map	Square Kilometers	Percent of total area (%)
Flat alluvial plain	46,0	53
Lateritic plain/interfluves	22,9	26
Escarpment/plateau	8,1	9
Seasonal flooded area (bas fond)	10,3	12
Total area	87,3	100

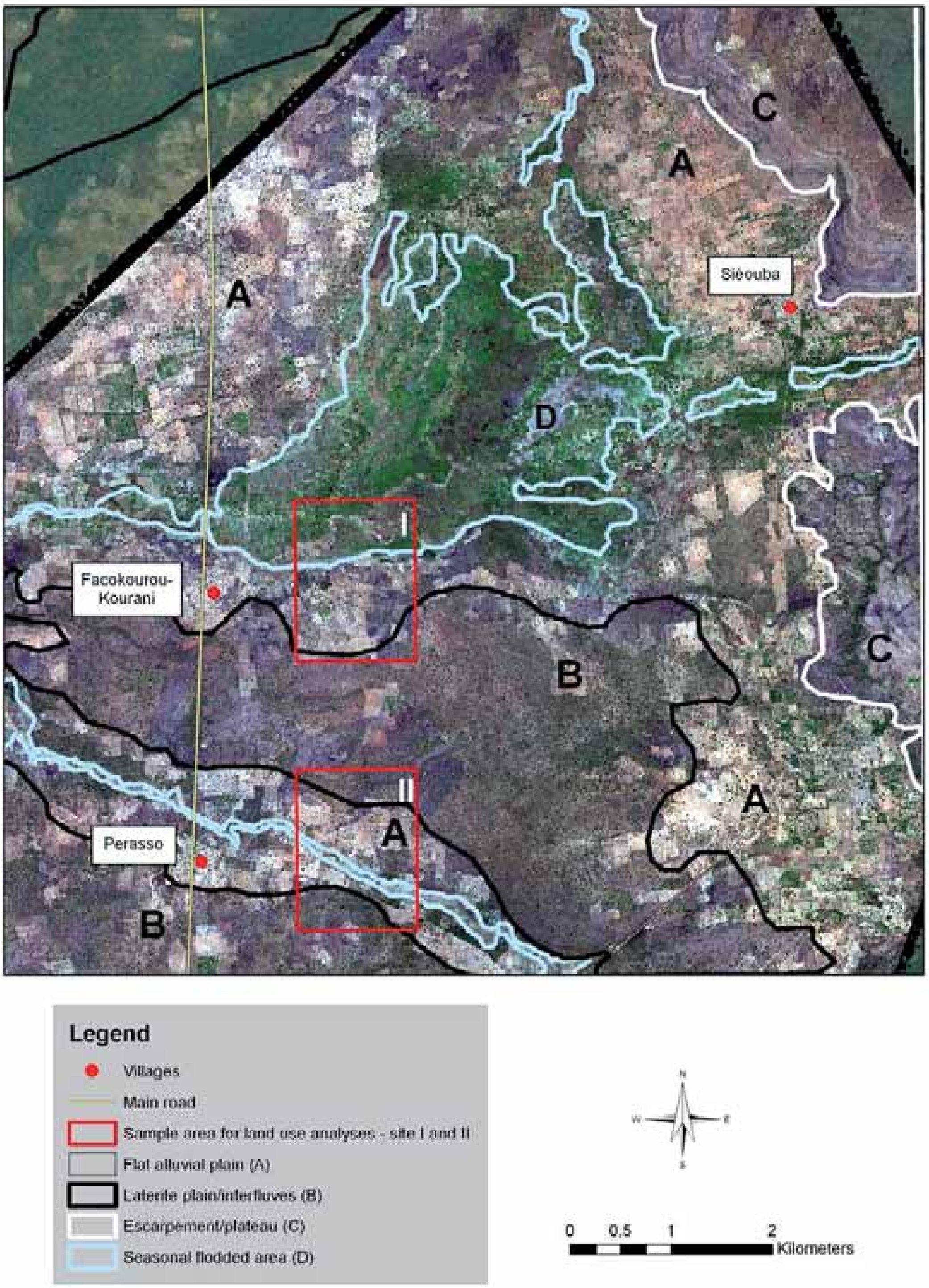


Figure 2 Landscape units in the study area.

7.2. Villages

Two different areas, including three villages, representing slightly different bio-physical settings, were chosen as the location for detailed surveys:

1) Representing areas with an existing high production of cassava, in the wet-lands as well as in the alluvial plains, two villages, Sièouba and Facokourou Courani, were selected. The two villages are located north-east and south-west of the large wetland (alluvial plain; *bas fond*) respectively (see figure 2 and site I in figure 3).

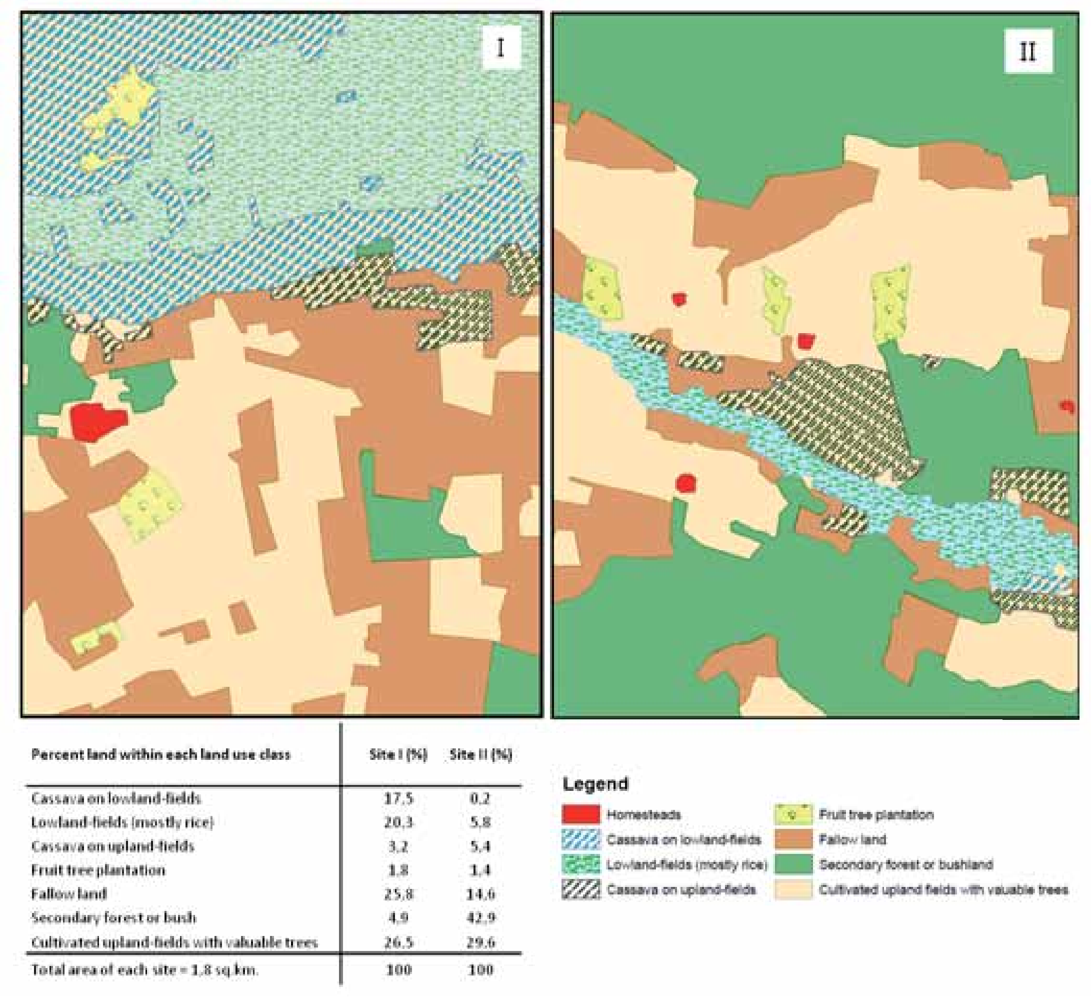
2) Representing areas with limited current cassava production and limited access to wetland, the village of Perasso was selected. It is representative of the southern part of Loulouni Commune and the area further south (towards the border to Ivory Coast). Small areas are cultivated with cassava, mainly in small/narrow wetlands in the proximity of rivers (see figure2 and site II in figure 3).

The population in all three villages is primarily composed of people from the Samogo and Xenofo ethnic groups, and most are smallholder farmers. Due to the long history of cotton production farmers are well organized and market-oriented. Their current cassava production is to a great extent directed towards an external market, and they even harvest ‘on demand’ when buyers request.

Within each village, approximately 30 households were been selected for the household questionnaire survey, using a stratified sampling scheme.

7.3. Land use history

Cotton used to be cultivated extensively on the sandy and – to a lesser extent – gravelly soils, and substantial areas of fallow land can be found where cotton used to be grown. Many of these fallow plots have an age of 5-10 years, as cotton production has declined over this period. Over the last decades cultivation has expanded into the large wetland area between Sieouba and Facacourou Courani. The crops grown in the wettest parts have mainly been rice and – to an increasing extent – cassava (see site I in figure 3). A lowering of the water table has been observed, allowing cultivation to expand into previously flooded areas.



Percent land within each land use class	Site I (%)	Site II (%)
Cassava on lowland-fields	17,5	0,2
Lowland-fields (mostly rice)	20,3	5,8
Cassava on upland-fields	3,2	5,4
Fruit tree plantation	1,8	1,4
Fallow land	25,8	14,6
Secondary forest or bush	4,9	42,9
Cultivated upland-fields with valuable trees	26,5	29,6
Total area of each site = 1,8 sq.km.	100	100

Figure 3 Land use in the two sub-areas, shown in figure 2

8. Results of the village level questionnaire survey

8.1. Production system

The arable production consists of a mix of cash crop and subsistence crop production. Previously cotton production with sale to the para-statal CMDT was the main dryland cash crop, but this has virtually been abandoned during the past five years due to falling profitability. Farmers with access to low-lying, wet 'bas-fond' land cultivate rice, yams and sweet potato besides cassava as the main cash crops, while farmers with fields located on the dry, alluvial plain cultivate groundnuts and maize as cash crops. Subsistence crops include millet, sorghum and maize as well as a variety of legumes and pumpkins.

As mentioned above, Sièouba and Facocourou Courani villages have greater access to wetland areas than Perasso (see table 2 and figure 3). Average farm size is 31% bigger in Sièouba and Facokourou Courani villages (17.7 ha vs. 13.3 ha in Perasso) and the proportion of the land which is currently cultivated is also higher (65% vs. 50% in Perasso). Furthermore, the proportion of land lying idle as long term fallow is much smaller (8% vs. 30% in Perasso). Thus, Sièouba and Facocourou Courani produce a greater surplus and is more commercially oriented than Perasso.

Table 2 Farm size, cultivated area and fallow

	Sièouba and Facocourou Courani	Perasso
Average farm size (ha)	17.7	13.3
Average cultivated area (ha)	11.5	6.7
Average short fallow (< 20 years) (ha)	4.5	3.3
Average long fallow (> 20 years) (ha)	1.5	3.3

A significant proportion of farmers in both sub-areas use inorganic and organic fertilizers. A common dosage is 100 kg of ammonium (N) and 50 kg of 'super complexe' (P) fertilizer/ha, at a price of 30-40.000 FCFA/ha. Short term (< 20 years) and long term fallow (> 20 years) is also used to allow soil nutrient content to regenerate after a period of cultivation.

Land ownership is a complex mix of individual and communal/clan ownership. The complexity mirrors the household composition, where nuclear families are united in extended households and have differential access to land and labour and other important resources according to their age and social ranking in the community. The majority of cassava farmers in the two sub-areas own the land where cassava production takes place, which means that they can decide on land management issues without interference from others (70% in Sièouba and Facokourou Courani villages vs. 92% in Perasso).

8.2. Cassava production in the study area

In figure 2 the main land units of the study area are outlined. Cassava production takes place in both the wetland areas (D), on the dry plains with sandy soils (A), and on the plateaus (B and C), yet the cassava production systems vary greatly between these land units: In the wetland areas and river valleys, the bonouma variant of cassava is produced, often permanently. On the sandy plains cassava is often part of a crop rotation involving also maize, sorghum and several other crops, and both the bonouma and attieké variants are grown, with an overweight on the latter. The plateaus are less intensively cultivated, yet cassava fields with the attieké variant are found. Generally speaking, bonouma is preferred on the silty soils, while attieké dominates on the sandy and gravelly soils. In terms of production, the ratio of bonouma to attieké area is approximately 4:1.

Bonouma has a 9-12 month crop cycle. It is a sweet variety which can be consumed after limited preparation (e.g. boiled). Attieké is short cycle variety (6-9 month). It is a bitter variety and needs several steps of processing before it can be consumed, to reduce the content of cyanide glucosides. It has been cultivated for approximately 10 years in the region. It was originally introduced by immigrants from Ivory Coast, where it has a long cultivation history.

In addition, the varieties abidjanka and agassi were cultivated in smaller amounts (less than 5 % of the production)

Table 3 Cassava in the study area.

	Sièouba and Facocourou Courani	Perasso
% of respondents cultivating cassava	100	83
Average cassava area (ha)	4.8	1.2
History of cassava cultivations (years of cultivation)	18	5,4

As seen from table 3, important differences were found between the two sub-areas. In Sièouba and Facokourou Courani villages, all respondents cultivate cassava, the cassava areas are quite large (average: 4.8 ha) and the crop has a long history of cultivation (average: 18 years). In contrast, 17% of the respondents in Perasso do not cultivate cassava, the average cassava area is relatively small (1.2 ha) and the cultivation is quite recent (5 years on average).

8.3. Crop calendar

In the case of bonouma in wetlands, planting generally takes place from July to November and the actual planting dates depends on the availability of land and labour (especially when work teams "entre-aide" are engaged). Crops are planted in mounds ("billon") or ridges promoting tuber development and avoiding flooding. After a few months weeding takes place, and weeds are integrated in the mounds/ridges. Fertilizer is supplied to the individual plants. Some farmers indicated that planting depends on soil humidity and may continue later than September. However, a certain moisture content is required for the 1st. weeding, which needs to be taken into account by the farmer when deciding on the planting period. The main period of harvest is from the beginning of the rainy season (May-June) to September. In the case of attieké, planting and harvest on the lighter soils can take place throughout the year. Farmers indicate that after the onset of rains, tubers increase in weight as the plant benefits from early rains, even after maturity.

8.4. Labour inputs

Cassava is cultivated with a combination of family labour, entre-aide and hired labour. Hired labour was used by 91% of the farmers in Sièouba and Facocourou Courani villages and the similar figure was 78% in Perasso (see table 4). The hired labour may be the village group (a "Ton") or other groups which are hired either on a temporary basis (daily or weekly) or for a fixed activity (e.g. field preparation). While cassava can be harvested during periods of low labour demand, most activities coincide with crop activities of other crops (planting during period of sufficient rainfall). This may lead to competition for labour, which can be a particular problem for households with limited labour availability. Cassava, and especially bonouma grown in wetlands, is a time consuming crop due to the labour intensive planting and harvest operations and 68% of the farmers in both sub-areas report that they use more time on cassava production than on other crops.

Table 4 Labour inputs in cassava production.

	Sièouba and Facocourou Courani	Perasso
Use more time on cassava than other crops (% of households)	69	68
Use hired labour (% of households)	91	78

8.5. Cassava yields

Average yield levels vary considerably between the two subareas. According to the questionnaire survey, the fertile bas-fond provides average yields of 11 t/ha to the farmers in Sièouba and Facokourou Courani villages, while yields are approximately 30% less in Perasso. Both yield levels are significantly lower than the national averages of 15-20 t/ha, according to FAO statistics..

Variations in yield are large between fields, from very low values on sandy soils (on the flat alluvial plain) cultivated with cassava for several years without use of fertilizers, to yields in the order of 20 t/ha on well managed wetland soils with adequate use of fertilizers. Field trials with new variants and cultivation techniques in the area are reported to give yields in the order of 30 t/ha. It should be noted that it is not unusual that cassava fields are not harvested at all, if there are no buyers on the market.

8.6. Farmers' interest in expansion of cassava cultivation

In both sub-areas, a vast majority of cassava farmers expressed an interest in expansion of their cassava production (90%). The question of the price incentive required to cause a substantial increase in cassava production remains. This has been addressed in several ways in our field work: Firstly the question was asked in the questionnaire survey. Secondly, the issue was discussed in interviews with individual farmers and with village representatives. Thirdly, the question was raised in group interviews with farmers, as part of the analysis of the cassava value chain. Further, household economic information on current sources of incomes and labour productivity may yield indirect information. Finally, the information on current prices obtained may be used as a basis for extrapolation to the hypothetical situation of a sharp increase in demand. Answers to hypothetical questions concerning the prices required to trigger production increase are likely to be flawed, due to farmers' tactical considerations and the lack of specificity of the conditions under which the production might take place. Not surprisingly, therefore, the answers obtained varied widely. In the questionnaire survey, the numbers given were high, and probably reflect tactical answers. The prices given are often twice current price levels, and, if real, certainly make production of bio-ethanol uneconomic. Interviews with farmers gave widely different numbers, reflecting both real differences in the preferences of individual farmers and tactical responses. Group interviews, allowing a discussion on the conditions of production, availability of land at village level etc, gave more consistent answers. We found that a price level of 30-35 CFA for the attieké variant harvested outside the wet season was realistic, assuming that farmers were guaranteed a quota and a price.

Still, responses in the questionnaires indicate that additional economic incentives may be required if the majority of farmers are to expand their cassava production into fallow areas and existing fields. A statistically significant difference ($p < 0.01$) across the three villages was observed. Post-hoc comparisons of means reveal that the mean price that would trigger an expansion is significantly ($p < 0.01$) higher in Perasso than in Sieouba and Facocourou-Courani. This further underlines that farmers in Sieouba and Facocourou-Courani are more eager to expand the cassava production beyond present levels than in Perasso.

The estimate of 30-35 CFA, required to trigger an increase in production, corresponds to the lowest prices currently obtained for Attieké, yet comparisons with the incomes generated from other cash crops (per unit of area and labour input) support that this would be economically attractive to farmers. This corresponds to the ‘break-even price’ mentioned above, making bio-ethanol production economically feasible, under a range of assumptions. It also corresponds to the highest prices obtained in SE-Asia in cassava production for bio-ethanol.

9. Assessing the environmental sustainability of bio-ethanol production

Assessment of sustainability requires that the environmental, economic and social dimensions are addressed. In the current context we will examine only certain aspects of the environmental sustainability, and we will focus mostly on the impacts on carbon stocks in vegetation and soil.

Environmental sustainability encompasses the following issues:

1. How will production of bio-ethanol from cassava affect net-emissions of GHGs, directly as well as indirectly, and locally as well as globally ? This includes also the estimation of direct and indirect land use effects: What vegetation /which crops will an expanded cassava production replace, what will be the indirect effects on land use (associated with land uses moving elsewhere, replacing other vegetation and crops), and what losses or gains in carbon storage in vegetation and crops will this entail?
2. Will expanding or intensified cassava production draw upon water and plant nutrient resources, and will this be sustainable ?
3. Will expansion of the cassava production area cause loss of biological diversity, locally or globally ?

4. Will the expansion of cassava production cause changes in the pollution with pesticides and insecticides and greater leaching of plant nutrients, with effects on ground- and surface water ?

As indicated, we will concentrate on the first of these four issues. This is because the latter three appear comparatively unproblematic:

Ad 2) Cassava production is not more demanding in terms of water use per unit of produce than the crops it replaces. Irrigation is not used. In order to obtain high yields, use of fertilizers is required, yet this is true for all crops.

Ad 3) Whether increased cassava production for bio-ethanol causes loss of bio-diversity depends, of course, on the direct and indirect land use changes caused by the expansion. We assess that only when forest is being replaced the biodiversity loss will be notable. Cassava only directly replaces forest in few cases, however indirect land use change effects cannot be ruled out.

Ad 4) Application of pesticides and insecticides in cassava production is presently not believed to be higher than for other crops. To the extent that cassava replaces cotton as a cash crop, the pollution by pesticides and insecticides may be expected to be reduced.

Thus we find it justified to focus only on the carbon effects.

10. Methodology and data sources

10.1. Likely land use changes

As the study area is dominated by cropland and fallow land, expansion of the cassava cultivation will mainly take place into presently cultivated land or into the fallow areas. In order to identify the likely land use changes if the cassava production were to expand, household based questionnaires (carried out by interview) were employed, as described above. Farmers were asked firstly to explain which areas they would use if expanding the cassava production and secondly what price per kg of cassava that would trigger an expansion of the cassava production. When farmers reported unwillingness to expand the cassava production, they were asked to mention the constraints for the expansion. The collected data on likely land use changes were analyzed using descriptive statistics.

10.2. Changes in above-ground carbon stocks due to land use/cover changes

The household based questionnaires were also employed to estimate changes in above-ground carbon stocks when expanding cassava production. Farmers were asked to indicate if they would preserve or remove trees in fields and fallow areas when expanding the cassava area. The insights obtained from the household based questionnaires were used to structure the inventory concerning the above-ground biomass. The data collection relating to the above-ground biomass was thus based on a systematic sampling design where the areas farmers reported they would use when expanding the cassava cultivation were visited. This included fallow areas and presently cultivated fields: when farmers reported that they intended to expand the cassava cultivation into fallow areas, they were asked to locate candidate areas. During the visits to fallow areas and presently cultivated fields, farmers pointed out which trees they would clear and which trees they would preserve, if they were to expand the cassava area. As farmers are maintaining 'useful' trees, data on species were recorded separately for the trees farmers are preserving and the trees which would be removed when expanding the cassava-cultivation. This sampling design was chosen in order to measure both the preserved and the removed above-ground biomass if farmers expand the cassava cultivation.

Biomass-/carbon stock assessments were carried out by spatial sampling. To sample the fallow areas, which usually extended over an area of 1–2 ha (the typical size of an abandoned field), 11 plots of 20 m*20 m were selected randomly. For the trees that would be removed when expanding cassava cultivation, the data recorded were the species and diameter at breast height (DBH) for all stems with DBH ≥ 0.05 m. In addition the age of the fallow was estimated, by inspection of vegetation development and by asking farmers about the cultivation history. A total of 65 'non-useful' trees were recorded at the 11 plots.

As the trees farmers plan to preserve when expanding the cassava production are fewer and have a more scattered distribution across the fallow areas and the agricultural fields, 16 plots of 1 ha were selected. DBH for all stems with DBH ≥ 0.05 m and species were recorded. A total of 134 preserved trees were recorded at the 16 locations.

To attain an independent verification of the results obtained in the field survey, trees were counted on high resolution satellite images from January, 2010. The number of trees was determined for areas of 1 ha within agricultural plots.

In order to estimate woody biomass, five different allometric equations were used. Their forms are compared in table 5. FAO1, FAO2 and FAO3 were developed by Brown (Brown, 1997), and each of these equations is associated with specific climatic zones regardless of species. The study area falls within the zone associated with FAO1, yet not far from the 1500 mm rain year^{-1} threshold. The last two models listed in table 5 were developed by Mbow (2009) on the basis of data from the Guinean and Sudano-Guinean savannas in nearby Senegal.

Table 5. Allometric equations for estimating biomass of tropical trees. Y = biomass per tree in kg, DBH= diameter at breast height. FAO1, FAO2 and FAO3 are developed by Brown (1997), whilst Quadratic and Polynomial are developed by Mbow (2009).

Equation name	Equation	Range in DBH (cm)	Climatic Zone
FAO1	$Y=exp(-1.996+2.32*ln(DBH))$	5-40	Dry areas, <1500 mm rain year^{-1}
FAO2	$Y=42.69-12.8(DBH)+1.242(DBH^2)$	5-148	Moist areas, >1500 mm rain year^{-1}
FAO3	$Y=exp(-2.134+2.530*ln(DBH)$	No range	Moist areas, >1500 mm rain year^{-1}
Quadratic	$49.84-(10.34*DBH)+(0.89*DBH^2)$	No range specified	The Guinean and Soudano-Guinean savannas in Senegal
Polynomial	$0.0225*DBH^3-0.5167*DBH^2+13.613*DBH-58.18$	No range specified	The Guinean and Soudano-Guinean savannas in Senegal

The five models are illustrated in figure 4. The moist zones equations (FAO2 and FAO3) give essentially the same biomass estimates up to a DBH of 65 cm. This is also the case with the Polynomial and the Quadratic equations. The dry zone equation (FAO1) gives lower estimates for all DBH's, but the upper limit of DBH is 40 cm in FAO1. In order to take these differences into account, the stem biomass was calculated for all recorded trees with a DBH of up to 40 cm using both the dry zone equation and the Polynomial equation. With a DBH of 40 to 60 cm, the difference is largest between the moist zone equations and the Quadratic equations, whilst after a DBH of 60 cm the Polynomial model gives the highest biomass estimates. As the study area is located in the dry zone, the Quadratic and Polynomial models are employed for trees with DBH's larger than 40 cm.

As in Fargione et al. (2008) and Williams et al. (2008), 50% of the dry wood biomass is assumed to be carbon.

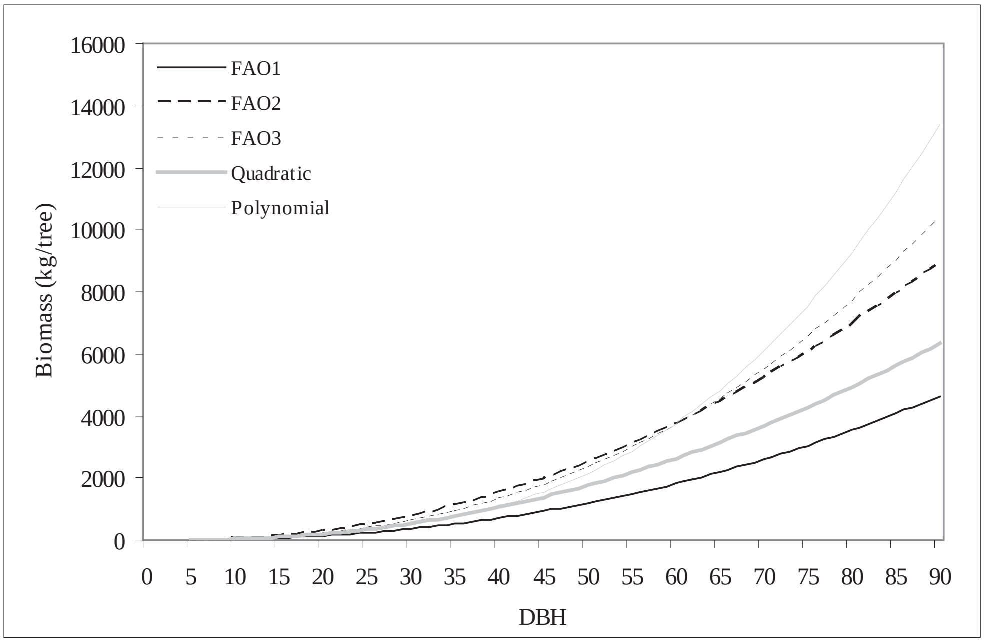


Figure 4 Allometric equations for estimating biomass of tropical trees. FAO1, FAO2 and FAO3 were developed by Brown (Brown, 1997), whilst Quadratic and Polynomial were developed by Mbow (Mbow, 2009).

10.3. Carbon debt caused by changing land use

Two approaches are feasible to assess the impacts on the carbon cycle when land use changes occur: One focusing on changes in pools and one on measuring fluxes. In the present case the first approach is chosen. This approach is based on the methodology recommended in IPCC (2006) concerning carbon stock change estimation. We calculate the changes in above-ground carbon stocks when fallow land is converted to cassava cultivation**.** We will not account for carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) emissions associated with applying fertilizers, since these emissions have not been measured in this study, but may be assumed to be small compared on the basis of estimates following the guidelines for international greenhouse accounting practice (IPCC, 2006). The chosen approach includes three steps:

- Estimation of carbon losses to the atmosphere caused by clearing trees, which is termed the ‘carbon debt’ (or rather a part of the ‘carbon debt’, since carbon losses associated with reductions in below-ground carbon stocks are not taken into account). It should be noted that it is not taken into account that some of the wood is either used for products (e.g. timber for houses) with a long life-time or used as wood fuel, presumably replacing other energy sources. Thus the calculated ‘carbon debt’ may represent an upper limit.
- Estimation of the reduced carbon emission to the atmosphere due to the replacement of fossil fuels by cassava-based bio-ethanol. This replacement can over time repay the calculated carbon debt.
- Calculation of the number of years required to repay the carbon debt.

The carbon debt is determined on the basis of the estimated carbon stock in the above-ground biomass, whilst the annual replacement rate is calculated by multiplying the cassava yields ha^{-1} in the case area with estimates of the cassava amount required for 1 litre bio-ethanol and a substitution ratio between gasoline and bio-ethanol. Finally, the repayment time is estimated by dividing the carbon debt by the annual carbon ‘repayment’, achieved when cassava-based bio-ethanol replaces fossil fuels.

10.4. Soil sampling and analysis

The main part of the soil sampling was carried out in the village of Sièouba, where all relevant soil types and land use histories were well represented. Group and individual interviews were carried out to determine what soil types the farmers distinguish between, and what land use changes are expected during an expansion of cassava cultivation. When an overview of the different likely land use change scenarios had been established, fields were visited and soil samples taken.

10.5. Soil sampling

A profile was dug (at the end of a mound/ridge in cassava fields), 50cm deep, 50cm wide and 50cm long. The different horizons in the profile were noted. Five volume specific samples were taken down through the profile for each 10cm interval, and in cassava fields a sample was also collected from the mound.

In wet rice or cassava fields, where the water table was above the level of the soil surface between mounds/ ridges, profiles could not be dug. Instead a plastic tube was hammered 50cm into the soil (at the end of a mound in cassava fields). The tube was then dug free and carried home. For most of the samples, the tubes were cut into 10cm intervals (the colour in both ends was noted) and the soil was gently tapped into a volume specific ring.

The samples were spread out to dry in the sun. Some samples needed grinding with a stone. Afterwards, the samples were divided using the pyramid division, weighed and packed before transported home to Denmark. In Denmark the samples were further divided and crushed using a ball mill. Total carbon was analysed at the laboratory of Physiological Ecology at the Department of Biology, University of Copenhagen on a LECO TruSpec Carbon Nitrogen Determinator.

10.6. Soil horizons

Cassava is cultivated in mounds/ridges of varying size (depending, among other things, on the labour available). The cassava cultivation system results in quite characteristic horizons, as there is both an active layer of soil in the mounds and beneath and in between the mounds. At every harvest, and subsequent new planting, the mounds are moved to the space between the previous mounds. Thus, the majority of the soil stays in the mounds, but some may be left behind. While weeding, some soil from in between the mounds, is mixed into the mounds. The soil carbon stock on cassava fields was calculated by adding the stocks for the mound and each 10cm interval to a depth of 50cm.

10.7. Statistical analyses

Data was analysed with the statistical program R using the methods described in Bibby et al. (2006). One-way analysis of variance (ANOVA) was carried out to test for a significant difference in the soil carbon stock to a depth of 50cm between the different land-uses in the scenarios. Similar analyses were carried out on C percentage. A comparison of the carbon stock under cassava cultivation in the different scenarios was also carried out.

The model tested in R is:

Model A: $Y_i = \alpha(Landuse_i) + e_i$, $i = 1,\ldots,N$

where $e_1,\ldots,e_N$ are independent and identically $N(0,\sigma^2)$-distributed random variables. It should be noted, that data is from at completely randomized design, which is not balanced. In order to attain a plot of residuals with variance homogeneity some of the responses need to be transformed before carrying out the one-way ANOVA.

11. Results

11.1. Expected land use/cover changes due to expansion of the cassava production

As described above, the amount of actively cultivated land per household average 7.6 ha in the study area, but range from 0.5 to 30 ha. A one-way ANOVA shows no statistically significant difference between the three villages. The sizes of the cassava plots range from 0.1 to 10 ha with a mean of 2.4 ha. A statistically significant difference ($p < 0.01$) across the three villages is observed and post-hoc comparisons of means reveal that mean plot size in Perasso is significantly lower than in Sieouba ($p < 0.05$).

As 77 of the 82 interviewed farmers are currently growing cassava, the cassava is already an important crop in the area. However, most farmers are interested in expanding the cassava area in the future due the abandonment of cotton production. When expanding cassava production beyond the present level, 74% of the current cassava farmers mention that the expansion is going to take place into fallow areas (figure 5), while 60% are expanding the cassava cultivation by replacing rice, maize, millet or sorghum in existing fields. 45% of the farmers report that they prefer expanding into both fallow areas and existing fields, whilst 88% of the farmers plan to expand either into the fallow areas or existing fields. The motivation for the interest in expanding the cassava production, the farmers explained, is associated with the income which increased cassava production can generate. Only 12 % of the farmers will not expand the cassava production to neither existing fields nor fallow areas. The reported reason for the unwillingness to expand cassava production into fallow areas and presently cultivated fields is lack of capital for hiring labour and buying inputs (mainly fertilizer) for the cassava production.

It should be noted that 'fallow land' refers to land that is abandoned from cultivation over the past years or decades. The shortest period of re-growth is one year, and the longest exceeds 20 years. The fallow areas have *kundje* (*Guiera senegalensis*) and *guesembe* (*Bauhinia rufescens*) as the dominant woody species. As we shal return to, farmers are protecting useful trees in the fields and fallow areas, primarily the *karité* (*Vitellaria paradoxa*), the *néré* (*Parkia biglobosa*), the *mango* (*Mangifera indica L.*) and the *allumeterie* (*Gmelina arborea).*The trees are selectively retained by farmers because of their use for food, medicinal purposes and shade.

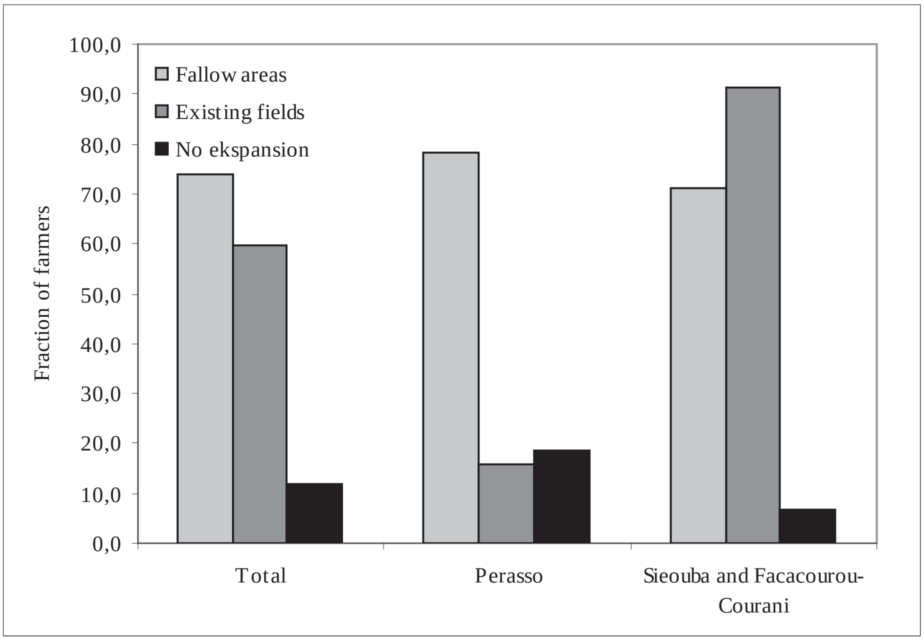


Figure 5. Attitudes among farmers to expansion of cassava into fallow areas or existing fields.

However, looking at the three villages separately the picture is more blurred. A chi-square test reveals that the percentage of farmers who intend to expand the cassava production by using fallow land does not differ significantly between the three villages, while the interest in expanding into existing fields differs significantly ($p < 0.01$) between the villages. 92% of the farmers in Facocourou-Courani and Sieouba intend to expand into existing field areas, while the percentage in Perasso is only 16%. The farmers in Perasso, who decline to expand the cassava production into existing fields, state that they prefer to keep their existing fields, presumably to assure food security, and that the soil type in these fields is not suitable for cassava.

Thus, the general tendency in the study area is that in the case of attieké, farmers prefer an expansion into the fallow areas, previously used for cotton production, or integration of cassava into the existing crop rotation with maize, sorghum and millet. This implies that impacts on local food security are small. On the other hand, expansion of bonouma production may compete for land with rice cultivation in the highly productive wetlands. Impacts of expanded cassava production differ between villages due to differences in land availability: In Facocourou-Courani and Sièouba farmers have fewer possibilities than the farmers of Perasso to expand the cultivated area, and thus they plan to expand into existing fields to a greater extent.

It might be expected that the interest in expanding cassava production would differ according to the access to land of the household. In order to characterize the farmers stating they would like to expand and the farmers refusing to expand, four independent-samples t-test are conducted. Firstly, the mean size of the active cultivated land is compared for farmers willing to expand the cassava production into fallow areas and farmers with no intentions of expanding into fallow areas. Secondly, the mean size of the cassava plots is compared for the same two groups of farmers. The third and fourth tests are also focusing upon the mean size of the active cultivated land and the cassava plots, but the two groups compared are the farmers willing to expand into existing fields and the farmers declining to expand into existing fields.

Table 6 Comparison of respectively the mean size of active cultivated land and the mean size of cassava plots for farmers interested in expanding the cassava production beyond present levels and farmers declining to expand.

Expansion area	Mean size of active cultivated land (ha)		Mean size of cassava areas (ha)	
	Yes	*No*	*Yes*	*No*
Fallow areas	8.5 ± 5.3	6.3 ± 3.9	2.5 ± 2.4	1.8 ± 1.4
Existing fields	8.7 ± 5.7	6.9 ± 3.7	3.3 ± 2.4	1.1 ± 0.9

No significant difference is observed when comparing the size of the active cultivated land for farmers willing to expand into fallow areas and farmers not willing to expand into fallow areas. In contrast, when comparing the size of the cassava plots for the two groups, there is a significant difference ($p < 0.05$). The mean size of the cassava plots is 2.5 ha for the farmers mentioning they would expand, whilst the mean size is 1.8 ha for the farmers refusing to expand (Table 6).

When comparing the farmers willing to expand into existing fields and farmers with no intentions of expanding into existing fields, there is no significant difference in the size of active cultivated land. A significant difference ($p < 0.05$) is however observed when comparing the size of the cassava plots. The mean size is respectively 3.3 ha and 1.1 ha for the farmers willing to expand into existing fields and the farmers declining to expand.

However, as the amount of cultivated land per household is well correlated with the size of cassava plots (R= 0.65, $p < 0.01$) with the strongest correlation in Sièouba (R= 0.88, $p < 0.01$) and the weakest in Perasso (R= 0.52, $p < 0.01$), this could indicate that in terms of expanding the cassava production it would be the farmers with the largest cultivated area and the largest cassava plots, who would expand the most. This implies that the farmers with good access to land, perceive expansion of cassava as a potential income-generating specialization, while farmers with less land may be more concerned with assuring local food sufficiency and security, and thus focus more on preferred food crops.

11.2. Impacts on above-ground carbon stocks when expanding cassava production

During the interviews and field visits it became evident that when expanding the cassava cultivation beyond present levels, farmers will preserve ‘useful trees’. When referring to useful trees, farmers identify trees providing food and medicinal uses. Trees giving shadow are also essential to retain, as farmers need a place with shadow when working in the fields. Only 8.5% of the farmers interested in expanding the cassava area report that they would remove all the trees when expanding. Conversely, 61% of the farmers state that they intend to maintain all the useful trees, whilst the remaining 30.5 % of the farmers are preserving particularly karité and néré. This clear tendency to preserve useful trees underlines the importance of distinguishing between the preserved and the removed trees when analyzing the effects on the carbon stocks in case of cassava production expansion.

Concerning the dry fallow lands, the average DBH amongst the 65 non-useful trees is 12 cm but range from 5 to 33 cm. Stocking density (number of tree stems per ha with DBH ≥ 0.05 m) varies from 25 to 525 trees ha^{-1} among the 11 plots with an average of 139 trees ha^{-1}. Employing the allometric model FAO1, average stem carbon stock estimate is 0.050 Mg C tree^{-1} which corresponds to 6.9 Mg C ha^{-1} when accounting for the stocking density. Plot values range from 0.7 to 16.2 Mg C ha^{-1} caused by the different ages of the fallow areas (figure 6), soil quality and possibly in grazing/browsing intensity. When applying the Polynomial model developed by Mbow (Mbow, 2009), the estimated carbon stock is 9.3 Mg C ha^{-1} with plot values ranging from 1.1 to 21.8 Mg C ha^{-1}.

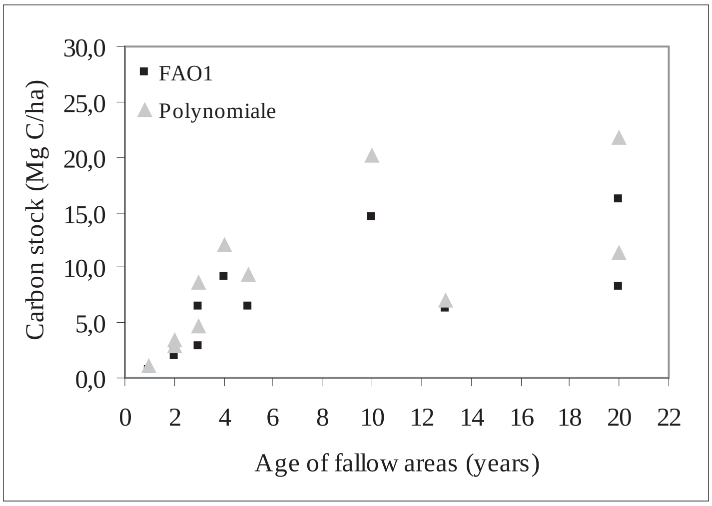


Figure 6. Above-ground carbon stock (Mg C ha^{-1}) in trees in dry fallow areas, which farmers intend to remove when expanding cassava production. The calculations are performed with the allometric model from FAO (Brown, 1997) and Mbow (2009).

The average DBH amongst the measured 134 useful trees farmers intend to preserve is 38 cm, but range from 9 to 91 cm. Stocking density varies from 4 to 20 trees ha^{-1} with a mean of 8 trees ha^{-1}. No significant difference is observed between the fallow areas and the agricultural fields. The measured stocking density corresponds to earlier estimates of tree density in agricultural land in Burkina Faso (Gijsbers et al., 1994; Kessler, 1992) and is furthermore confirmed by the tree counting using high resolution satellite images. The mean estimated C stocks are respectively 0.832 and 0.607 Mg C tree^{-1} when employing the Polynomial and the Quadratic model, which equals 7.0 and 5.1 Mg C ha^{-1}, when accounting for the stocking density.

Hence, our results indicate that studies assuming that the total above-ground biomass in fallow areas will be removed entirely when taking these areas into cultivation would overestimate the above-ground carbon loss by 42%, as illustrated in figure 7. However, as many farmers prefer to expand production into fields which have been fallowed for a relatively short period, in the order of 5 years, the fallow areas with the lowest ages are the most likely to be used when expanding. When taking this into consideration, the assumption that a total removal of the above-ground biomass would take place would imply an overestimation of 52% of the carbon losses caused by land use change.

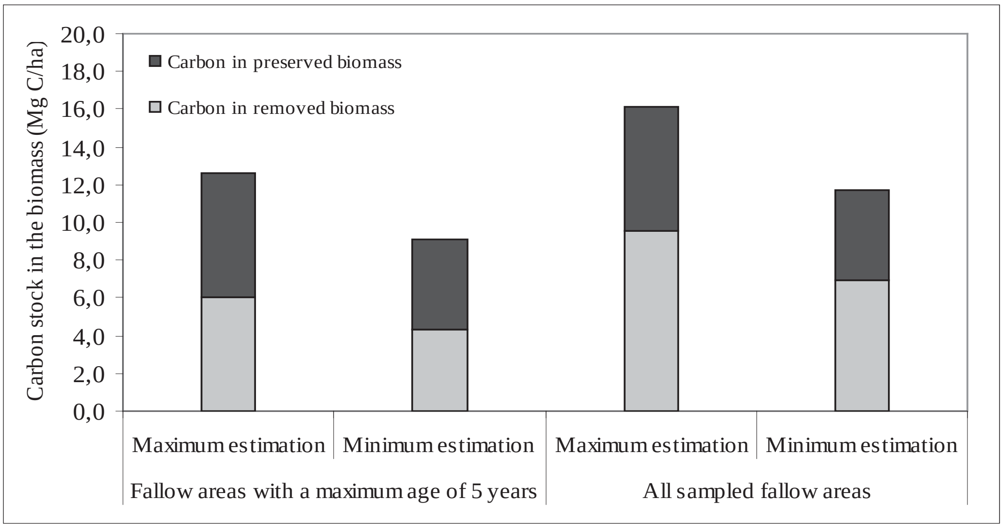


Figure 7 Above-ground carbon stock (Mg C ha^{-1}) in the biomass farmers intend to preserve and remove when expanding cassava production. Maximum represents the calculations with the Polynomial allometric model, whilst minimum represents calculations with the FAO1 model for the removed biomass (DBH<40cm) and the Quadratic model for the preserved biomass (DBH ranging from 9 to 91 cm).

11.3. Carbon debt repayment time

When computing the carbon debt repayment time (for the above-ground carbon losses only) the loss of carbon caused by land use change, estimated above, should be divided with the annual net reduction in carbon emissions to the atmosphere caused by replacing fossil fuels by bio-ethanol. To estimate this net reduction the annual emissions caused by the cultivation practice, not the least the use of fertilizers, is required. Using the actual amount of applied fertilizers in the study area and the IPCC guidelines of emissions from fertilizers, the emissions correspond to less than 0.06 Mg C/ha per year. Given the uncertainties involved and the fact that this emission amounts to only 0.5-1.5% of the carbon emissions caused by changes in above-ground biomass, the emission has been omitted from our further calculations.

As up to 7 kg of fresh cassava roots are needed to make 1 litre bio-ethanol (Nguyen et al., 2007; Silalertruksa et al., 2009), a yield of 9.3 Mg cassava roots ha^{-1} for the bonouma variety and 9.7 Mg ha^{-1} for the attieké result in respectively 1239 and 1292 litre bio-ethanol year^{-1} ha^{-1}. These amounts of bioethanol can replace 805 and 840 litre gasoline, as the substitution ratio between gasoline and ethanol is 1:0.65 (Henke et al., 2005). This replacement implies a carbon benefit of 0.59 Mg C year^{-1} for the bonouma and 0.61 Mg C year^{-1} for the attieké (assuming that the burning of 1 l gasoline emits 0.00267 Mg CO_2 (EPA (United States Environmental Protection Agency), 2005)). As the difference between the two varieties is insignificant, the carbon debt and the number of years to repay the carbon debt are calculated using the annual repayment rate for the bonouma, as this is the dominant variety in the study area.

Our results show that converting fallow areas to cassava cultivation results in carbon debts of 6.4 to 7.1 Mg C ha^{-1} (depending on the allometric model employed) when farmers are maintaining the useful trees. Hence, it would take between 12 and 14 years to repay the carbon debt (figure 8). A sensitivity analysis reveals firstly, that if farmers only are using the fallow areas with a maximum age of 5 years, it would take between 8 and 12 years to repay the carbon debt. Secondly, it shows that studies assuming a total removal of the above-ground biomass in fallow areas when taking these areas into cultivation will result in an estimate of 21 to 25 years for repaying the carbon debt. If farmers replace other crops by cassava, there is little or no reduction in above-ground carbon stocks, since the trees in the fields are not affected. Hence, there would be no carbon debt.

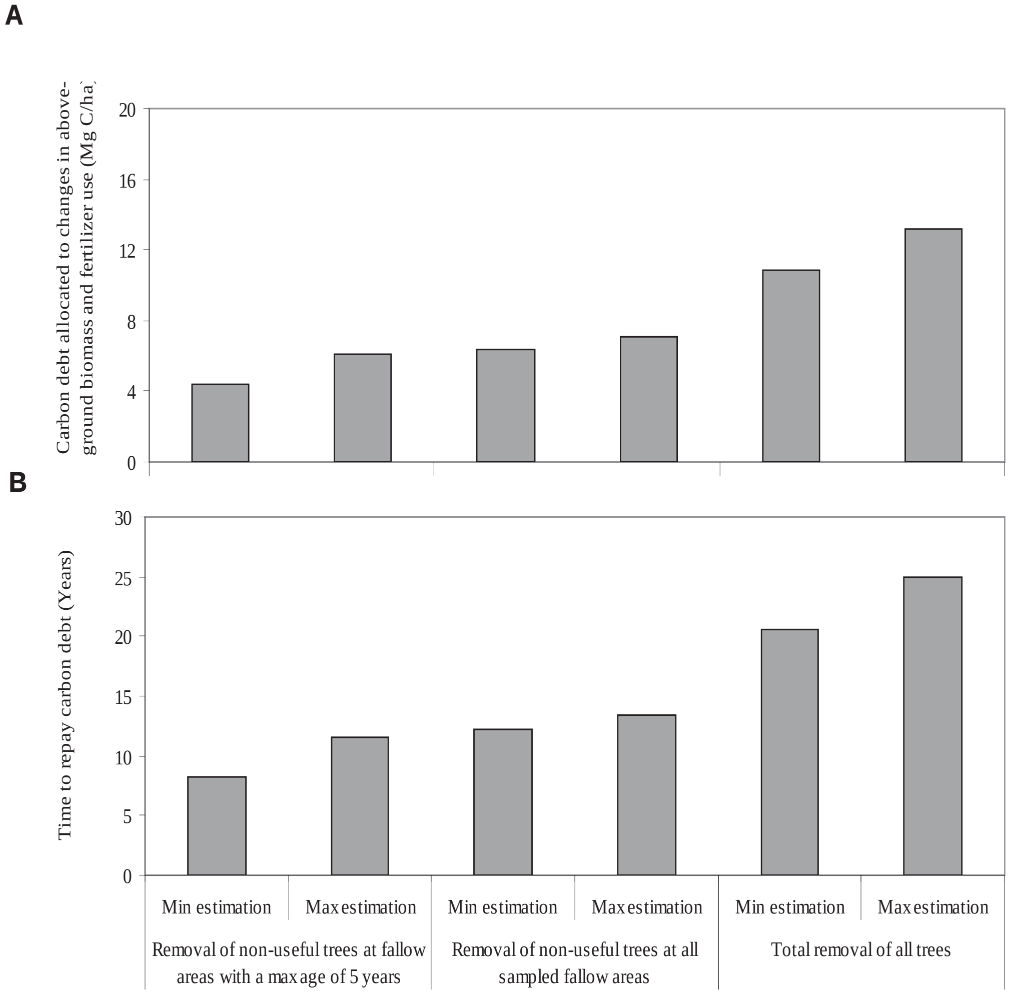


Figure 8 Carbon debt and repay time for three scenarios for converting fallow areas to cassava cultivation. Maximum represents the calculations with the Polynomial allometric model, whilst minimum represents calculations with the FAO1 model for the removed biomass (DBH<40cm) and the quadratic model for the preserved biomass (DBH ranging from 9 to 91 cm). (A) Carbon debt allocated to changes in above-ground biomass and application of fertilizers. (B) Number of years after conversion to cassava cultivation required to repay the carbon debt when displacing gasoline with bio-ethanol.

12. Changes in below-ground carbon stocks

12.1. Root carbon pool

Very little information is available on the size of the root carbon pool and how it is affected by clearing of trees. We will make the standard assumption that the 'root-shoot ratio' is 1:1, and that all root carbon is eventually lost when fallow is replaced by cassava, the above-ground carbon losses reported above may simply be doubled, causing repayment times to be doubled as well. This is obviously a crude assumption, but until more empirical work on the root carbon pool becomes available this is a best estimate.

12.2. Soil types

Based on group interviews, different soil types were identified, including "lè bogo" and "tien tien". In the Bambara language, "lè" means "wet", "bogo" means "soil", "tien" means "sand". Lè bogo, located in the low lying areas ('bas fond'), is more clayey than tien tien and may suffer from drainage problems. During the rainy season the water level in wetlands with lé bogo may be high, i.e. up to 10-20cm above the soil surface between the mounds/ridges. The sandy tien tien soils cannot retain much water. They are located between the wetland areas and the escarpment, see figure 1.

12.3. Scenarios of land use change considered

In Sièouba, three different scenarios for land use changes associated with future expansion in cassava cultivation have been examined. On lè bogo, the scenario involves that the farmers will substitute fallow and rice with bonouma. On tien tien soils they would expand the cassava cultivation on fallow lands. The first years after cutting down the fallow, they would cultivate attieké. However, after earning money on the attieké production, they might buy fertiliser and change into bonouma. An artificial timeline (chronosequence) for each scenario was established containing three points with each three to four replicates. The starting point is the reference soil, i.e. the current land use which is expected to be replaced by cassava. The two next points on the timeline represent respectively the short (2-3 years) and long term (5-10 years) cassava cultivation in sequence.

12.4. Calculation of changes in carbon stocks

The calculated soil carbon stock to a depth of 50cm on an area of one ha lies between 33 to 74 Mg C/ha (see Figure 9).

The statistical analysis shows no significant change in the soil carbon stock under a land use change from fallow to cassava on tien tien or from rice to cassava on lè bogo. However, when substituting fallow for cassava on lè bogo, a significant (*, $p = 0.02$) increase in the soil carbon stock can be expected – especially on the short term (within the first 2-3years). There is no significant difference between the carbon stock under the short and long term cassava after fallow on lè bogo. The estimates show that there is approximately 50 Mg C/ha stored under fallow on lè bogo to a depth of 50cm, 64 Mg C/ha under the short term cassava and 72 Mg C/ha in the case of the long term cultivation of cassava.

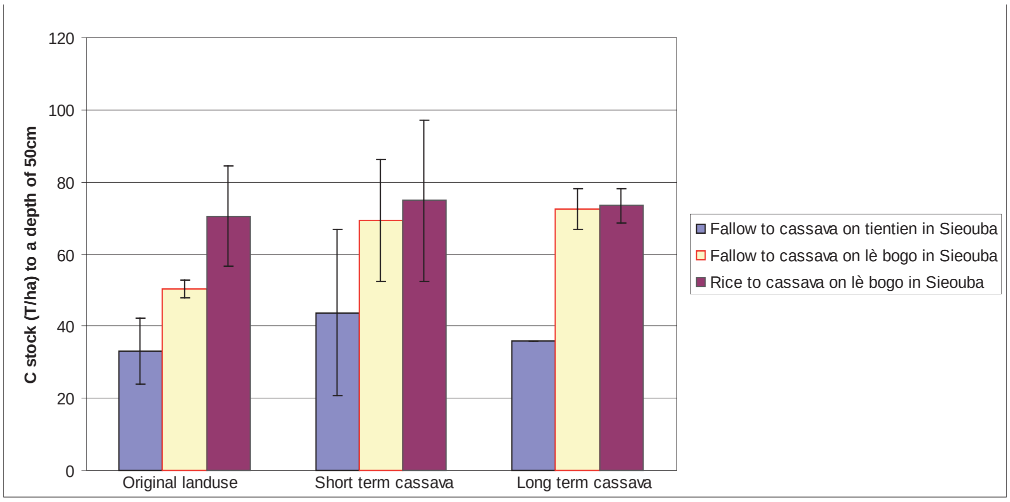


Figure 9 Carbon stocks in the upper ½ m of soil for three scenarios of land use changes

When short and long term cassava (with similar land-use history and soil-type) are pooled, the one-way ANOVA shows that the carbon stock is significantly (***, p=0.0003) larger under cassava cultivation on lè bogo (respectively 69 Mg C/ha after fallow and 73 Mg C/ha after rice) than on tien tien (38 Mg C/ha).

Figure 10 illustrates the percentage C content in the A horizon on the different land uses and soil types. The statistical analyses show, that there is no significant difference between the C percentage in the A horizon before and after the land use change from fallow to cassava on tien tien and from rice to cassava on lè bogo.

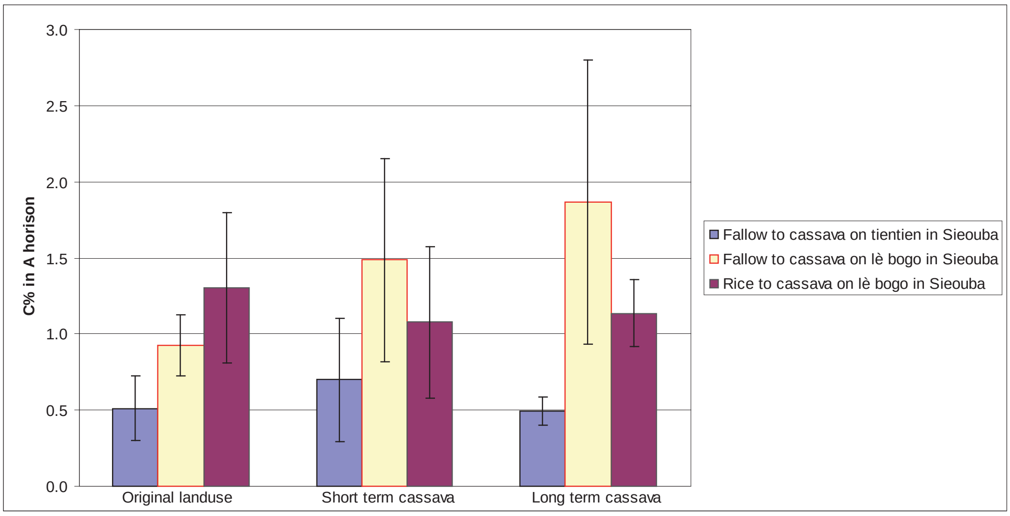


Figure 10 Carbon concentration (in %) in the A-horizon for three land use scenarios

However, there is a significant increase in the C percentage (*, p = 0.09) in the change from fallow (0.91 % C) to short term cassava (1.39 % C) on lè bogo, and even more so (*, p = 0.02) from fallow to long term cassava (1.66 % C), though there is no significant different between short and long term cassava. There is no significant change in C percentage in the B horizon between fallow and cassava on lè bogo.

12.5. Discussion of changes in soil carbon stocks

The results of the six weeks of fieldwork carried out in Sieouba show that the soil carbon stock measured is quite consistent with the values in the updated global carbon map from UNEP (Sharlemann et al. 2009). However, it also shows big variation in soil carbon stock within a very limited area, indicating that soil type and land use have important impacts on the soil carbon stock.

If the cassava cultivation should be expanded in this area in the future, replacing fallow on tien tien and lè bogo and rice on lè bogo, no decrease in the C stock to a depth of 50cm is likely to occur. On the contrary, an increase in the C stock after fallow on lè bogo can be expected. The increase in C% is limited to the A horizon. This could indicate that it is the changes in management, when bringing the land into cultivation, that result in the increase of carbon. Fertilisation increases the production of green matter and the weeding between the cassava mounds results in frequent incorporation of green manure into the soil. However, the standard deviation on the estimates is considerable, implying that changes are only statistically significant in a few cases.

It should also be noted, that cassava fields probably emit less CH_4 than rice fields, because cassava fields are flooded for a short period and only partly. Further analysis will be required to test this.

13. Discussion, conclusions and policy implications as concerns impacts on carbon stocks

Detailed empirical work in a particular location, as done in the present study, is required to inform the debate surrounding carbon emissions and land use changes caused by expanding biofuel production and to support policies on bio-fuel development. The following conclusions can be derived from the results presented:

- Expansion of cassava production for bio-ethanol is likely to lead to conversion of fallow areas, some formerly cultivated with cotton, to cassava. In other cases expansion will involve replacement of other crops, or intensification of crop rotations.
- The estimates of the reduction of carbon stocks in above-ground biomass, caused by the transformation of fallow into cassava, are in the order of 4 – 13 Mg C ha^{-1}, depending on (a) the age of the fallow, (b) the allometric equation used and (c) whether all trees are removed or the larger, useful trees are preserved.
- The replacement of fossil fuels by bio-ethanol from cassava grown in fallow fields will cause a reduction of emissions in the order of 0.5 Mg C ha^{-1} $year^{-1}$.
- This implies that the estimate for the 'repayment time' for the 'carbon debt' associated with the above-ground biomass loss is in the order of 8–25 years.
- Very little can be said about the carbon pool in the root biomass, but we assume that its size, and the changes associated with clearing of fallow vegetation, are of the same order of magnitude as found for the above-ground pool, leading to a doubling of the 'repayment time'

- Changes in soil carbon stocks, associated with increased production of cassava in both wetland with lè bogo (bonouma) and on the plateaus with tien tien soils (mostly attieké), are relatively small and do not affect the repayment time significantly. The reduction in CH_4-emissions caused by replacing rice by cassava in wetlands might be significant but requires further study.

The presented carbon repayment time may be considered low in the context of other bio-fuel production schemes. The results largely confirm the conclusions of Gibbs et al (2008) using a new database of crop locations and yields, along with updated vegetation and soil biomass estimates. Employing a similar cassava yield and bio-ethanol conversion factor, they estimate a repayment time of respectively 19 and 50 years, when converting shrubland and grassland to cassava in the dry tropics of sub-Saharan Africa. As the fallow land in our study area is not strictly shrubland or grassland (nor 'dry'), a rigorous comparison is however not possible. Our study differs also from Gibbs et al (2008) as we are accounting for the preservation of useful trees.

13.1. Uncertainties

As mentioned, knowledge of carbon storage in below-ground biomass is sparse, as the standard method for measuring root biomass is extremely labour intensive (Bruun et al., 2009) and empirical data representative for the study area are not available. As concerns soil carbon losses, Elberling et al. (2003) found values of carbon losses in the order of 11 Mg C ha^{-1} (over a 40 year period) when fallow or savannas is cultivated in a slightly drier environment. Regarding the root:shoot ratio, Mokany et al. (2006) have suggested a root:shoot ratio of 2 for shrublands. Both estimates should, however, be viewed with caution, as the soil carbon losses may vary according to ploughing depth etc., and the root:shoot ratios found by Mokany et al. (2006) for shrubland were ranging from 0.3 to 4.3 due to factors like water and nutrient availability.

Several issues need further study in environments comparable to the study area, in order to provide more precise estimates of carbon losses and repayment times:

- A validation of the allometric equations would be required.
- Empirical studies of the ratio of below- to above-ground biomass.
- Assessment of the effects of expanding cassava production into wetlands on CH_4 emissions.
- Empirical estimation of changes in N_2O emissions associated with fertilizer use in cassava fields. Such analysis is ongoing
- Analysis of the possibilities of increasing cassava yields beyond the observed level. Yields in the order of 20 - 40 Mg ha^{-1} are reported in similar environments, which would reduce repayment times substantially.
- The by-products from the cassava and the bio-ethanol production are likely to replace other products, e.g. for animal fodder, and the consequences of this for carbon stocks/fluxes should be counted in.

13.2. Policy implications

The main findings on environmental sustainability in this study have implications of policy relevance:

Firstly, the 'carbon debt' and 'repayment time' associated with increasing cassava production to feed bio-ethanol obviously depends on the land use changes involved: If cassava replaces forest, carbon debts are large and the repayment time extremely long.

However, this seldom happens. If cassava replaces fallow with an age of 10-15 years, the repayment time (assuming current yield levels) is in the order of a few decades, and if it replaces other annual crops there is no carbon debt. In the case of replacement of fallow by cassava, which is a likely pathway of change in the study area, it is worth noting that much of this fallow was under cultivation with cotton 5-10 years ago, before the collapse of the cotton value chain in Mali, and the proper estimation of the carbon debt will therefore depend on the choice of reference year. Seen from the farmers' perspective, they are replacing one crop, cotton, with another, causing no carbon debt. Navigating the waters between supporting a developing cassava-market based on fallow areas and minimizing unintended carbon emissions is thus a major challenge that policy makers should be aware of.

Secondly, while it is often assumed that when expanding the cultivated area the entire carbon stock in the woody vegetation is lost, we argue that this is not the case. If preserving what the farmers perceive as 'useful trees' about half of the carbon stock may be maintained. This practice should be preserved and promoted.

Thirdly, in order to achieve sufficiently high yields cassava must be fertilized, giving rise to both N_2O emissions and water quality effects. The net effects of land use change depends again on the reference chosen, be it cotton or fallow.

14. Social impact and sustainability

The social impacts and sustainability of increasing bio-energy production have been extensively debated, as mentioned in the introduction. We will address the following questions:

- What are the likely impacts of cassava-based bio-ethanol production on poverty, livelihoods ?
- How are the cassava value chains structured, and what are the implications hereof on the social consequences of cassava-based bio-ethanol production ?
- Will existing inequalities (ethnic, social, age and gender related) in the access to natural resources and income opportunities be affected by the establishment of cassava-based bio-ethanol production ?
- Will food security at local, regional, national and international levels be compromised by establishment of a cassava-based bio-ethanol production ?

14.1. Impacts on household economy and local livelihoods

Information on the impacts of the hypothetical increase in cassava production for bio-ethanol was obtained from household questionnaires, semi-structured group interviews and in-depth interviews with informants. As mentioned above, cassava is already an important part of the local economy, especially in Sièouba and Facocourou Courani. The main problems, related to household economics, encountered by farmers are

- An insufficiency of incomes, following the collapse of the 'cotton economy',
- the uncertainty associated with the demand for cassava on the market, implying that many cassava fields are never harvested, causing loss of invested inputs, and
- low cash incomes during the dry season, where the demand for cassava is small and particularly unstable.

Therefore a stable, guaranteed, all-year market for cassava and a price guarantee are very much welcomed. As discussed above, the questions remains, however, whether the price offered for cassava for bio-ethanol will be high enough to stimulate production. If not subsidized, a profitable bio-ethanol production is unlikely to be feasible unless cassava is available at a price not exceeding 30-35 CFA/kg. The statements from farmers vary on this issue, yet it appears likely that a guaranteed price of 30 CFA/kg for a contracted amount of cassava per household will generate the required increase. No other crop in the study area is likely to produce a guaranteed gross value of 300-600.000 CFA/ha. Farming under contract, as outlined here, has the additional effect that use of labour- and capital inputs, including fertilizers, becomes less risky. This may be expected to lead to increasing yields.

An increase in the area cultivated and/or in labour intensity will require that labour resources are available at the appropriate time. According to the responses to the questionnaires and the interviews, the majority of farm households claim to have abundant labour. In view of the concentration of agricultural tasks in the rainy season, it may, however, be doubted that this surplus of labour exists in the months July-September, where most of the effort in the harvest, field preparation (including mound/ridge building) and planting of bonouma is concentrated. The high prices obtained for bonouma in the wet July-September season (> 45 CFA/kg) imply that farmers will give priority to this production. On the other hand, it appears very likely from the responses that abundant labour resources are available outside the rainy season.

Both the cost and the labour considerations suggest that the production of cassava for bio-ethanol should primarily take place in the sandy plains and interfluves, and that the attieké variant, which can be harvested and planted all year, will be the best suited.

14.2. Cassava value chain analysis

The following results as concerns the cassava value chain(s) were derived from direct observation, interviews carried out during a mission in November 2010, supplemented with data from questionnaires:

- It was observed that the cassava value chain may effectively be divided into two distinct strands: One concerning (almost) exclusively the bonouma variant of cassava, and one concerning (almost) exclusively the attieké variant.
- The bonouma strand (approx. 80 % of the cassava production) is characterized by harvesting mainly taking place in the rainy season (July – September) with minor amounts being harvested in April-June and October – November. The bonouma is mainly transported as whole roots to markets in the North, in particular to Segou and Mopti, where it is used for human consumption in the rainy season when other food items are in short supply. The prices offered to farmers by traders vary (in the interval 30-100 CFA/kg) but are generally relatively high (>45 CFA/kg).
- The attieké strand (approx. 20 % of the production) is characterized by year-round harvest (probably reduced amounts in the rainy season when labour is invested in bonouma harvesting and planting). Attieké is mainly bought by women's groups processing it to the product 'attieké', which is either sold for immediate consumption in 'wet' form or dried. It is consumed locally, and not the least in Sikasso. Smaller amounts are sold in Bamako, yet the major source of

attieké in Bamako is imports from Cote d'Ivoire. The prices offered to farmers vary less than in the case of bonouma, generally in the 30-45 CFA/kg interval.

- Since bio-ethanol production requires a steady flow of feedstock over the year, it cannot be based on bonouma, unless the agricultural practices are changed significantly. Expansion of bonouma production for bio-ethanol may be possible, yet it would compete with its present use for food in the Segou-Mopti area, and the prices obtained in the current bonouma trade are so high that bio-ethanol production cannot compete.
- Attieké production matches better with the requirements of bio-ethanol production. The price level is closer to being compatible with the level which is realistic in relation to bio-ethanol production.

Thus the value chain study leads to the conclusion that it would be preferable to concentrate on attieké when planning feedstock production for a bio-ethanol production facility. Fortunately, this coincides with the findings based on cost and labour considerations. The principle is outlined in figure 11.

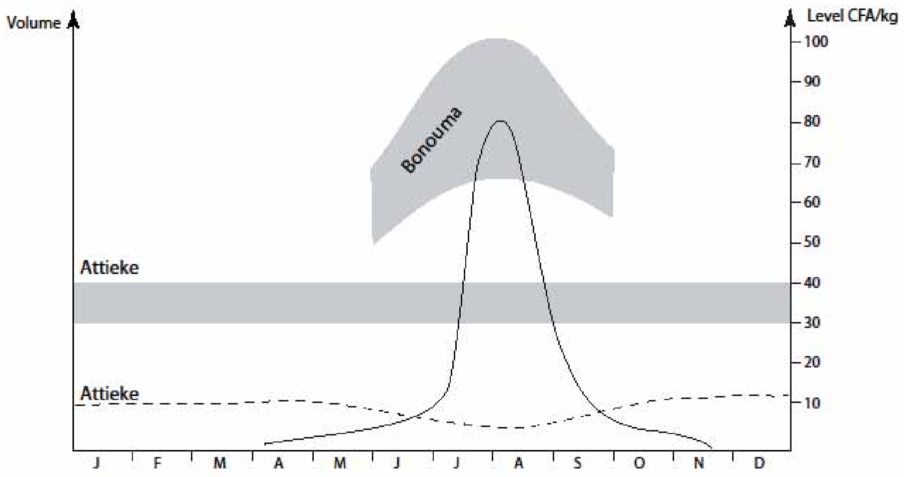


Figure 11 Variations over the year in production volumes and price-levels of bonouma and attieké varieties of cassava. Full and dotted lines show relative volumes, the shaded areas show the price intervals

The current cassava production in the villages is sold to traders. In the case of bonouma, traders come from both Sikasso, Segou and Mopti during the high season (July-September), while the year-round trading of attieké is handled by traders and transporters from Sikasso, and mostly sold on the market in Sikasso. Traders are associated with 'hosts' in each village. These hosts receive demands from traders and organize that the requested amount of cassava is delivered at the right time and place.

They also negotiate a price. The hosts thus play a key role in organizing the trade. A bio-ethanol production unit may build on this system, or it may alternatively base themselves on contacts to cooperatives. Cooperatives are well-known in the study area, yet cooperatives focusing specifically on cassava production and trade are still in their infancy in the area.

14.3. Equity impacts

The expected differential effects of establishing bio-ethanol production in the area on incomes and access to resources may be derived from the results reported:

- Households with good access to land are likely to be in a good position to take advantage of increased income opportunities, causing income differences to increase. Such differences exist both within each village and between villages. With respect to the latter, a village such as Perasso, with relatively large land resources with ‘tien tien’ soils, should be in the best position to benefit from increased all-year demand for attieké. However, even immigrants from elsewhere in Mali can obtain land for cultivation, indicating that there is currently no acute shortage of land. This is further supported by the relatively large fallow areas.
- The farmers which are also involved in the trading of cassava, as traders, hosts or transporters, will be strongly affected by any change in the existing system of trading. They can either experience greater opportunities, if the existing system is used by the company operating the bio-ethanol production facility, or their position may be eroded, if this system is replaced by alternatives, be it direct contacts between individual farmers and the company or cooperatives, acting as intermediates. Interviews, especially in Sièouba, indicated that the current trader/host system is being challenged by upcoming cooperatives. Further studies are underway, investigating this issue in greater detail. It should be noted that if the bio-ethanol production is only based on attieké variety, as suggested here, the bonouma value chain may not be affected significantly.

14.4. Food security implications

It follows from the above that an increased demand for cassava, especially attieké, for use in bio-ethanol production will influence the local agricultural production and the economic situation of households significantly. In terms of the effects on local food security, at household and village level, we will argue that while an increase in the area cultivated with attieké may partly happen at the expense of food crops, especially by increasing the role of cassava in the crop rotation, it appears unlikely that this will have negative impacts on local food security. The reasons are the following:

- The study area has an agricultural production exceeding the local demand for food.
- There are fallow areas available (some of them former cotton fields) which may be brought into use if required.
- Cassava is also a (highly productive) food crop, which may be used for local consumption in a food crisis. Actually, cassava is locally considered a ‘security crop’ of importance for human consumption in drought years.
- With higher and guaranteed incomes from cassava, the use of mineral fertilizers is likely to increase, causing an increase in yields.

Questions about this subject were raised during group interviews, and there was broad consensus that no local food security problems were likely to occur.

As discussed above, cassava, and especially bonouma, has great significance in relation to filling the 'hunger gap' in the Segou and Mopti regions further north. Interfering with this, strongly seasonal, value chain may therefore have considerable food security implications. This may be avoided by basing the bio-ethanol production only on attieké. The question is how this may be achieved, since it might appear difficult avoiding interference when bonouma is equally (if not more) useful as a feedstock for bio-ethanol production. We suggest that the solution lies in (a) only contracting farmers to produce attieké, and (b) relying on the market forces which guarantee that farmers will give priority to satisfying the demands for bonouma in the July-September period, simply because the prices are much higher than those offered by the bio-ethanol producer.

Apart from contributing to filling the hunger gap in the Segou and Mopti regions, cassava from the study area contributes to covering demands for the cous-cous like attieké product locally and in Sikasso. As mentioned this production is mainly in the hands of women's cooperatives at village level and in Sikasso. This demand may compete more directly with the use of cassava for bio-ethanol, but it is likely that the cooperatives would be able to pay a higher price than the bio-ethanol producer, assuring that their demand would be covered. There is likely to be opportunities for collaboration between the cooperatives and the bio-ethanol producer, assuring the stable supply of cassava for this purpose.

15. Climate change sensitivity analysis

The analysis of the sensitivity of a cassava-based bio-ethanol production in southern Mali comprises:

- A desk-study of climate model output, both information from GCMs, reported in IPCC 4AR, and RCMs, extracted from the data-bank of the ENSEMBLES project.
- Interviews with farmers on climate sensitivity of the cassava production in different parts of the study area.
- Interview with Dr. Daouda Zan Diarra from 'Direction National de la Meteorologie' in Bamako

The second part was mainly carried out during the mission on soil carbon impacts of cassava production. The third part was carried out during the mission in November 2010.

During the field work the farmers involved in the soil sampling were asked about whether the cassava production may be said to be vulnerable to changes in climate, in particular rainfall. Not surprisingly, most farmers reported that the yields obtained in the drier areas were affected by rainfall, while fields in the wetlands were less affected. It was recognized that the water level in the wetlands had been slightly lower since the drought of the seventies, allowing cultivation to advance into the wetlands. Cassava requires that the mounds, in which cassava is planted, are not flooded.

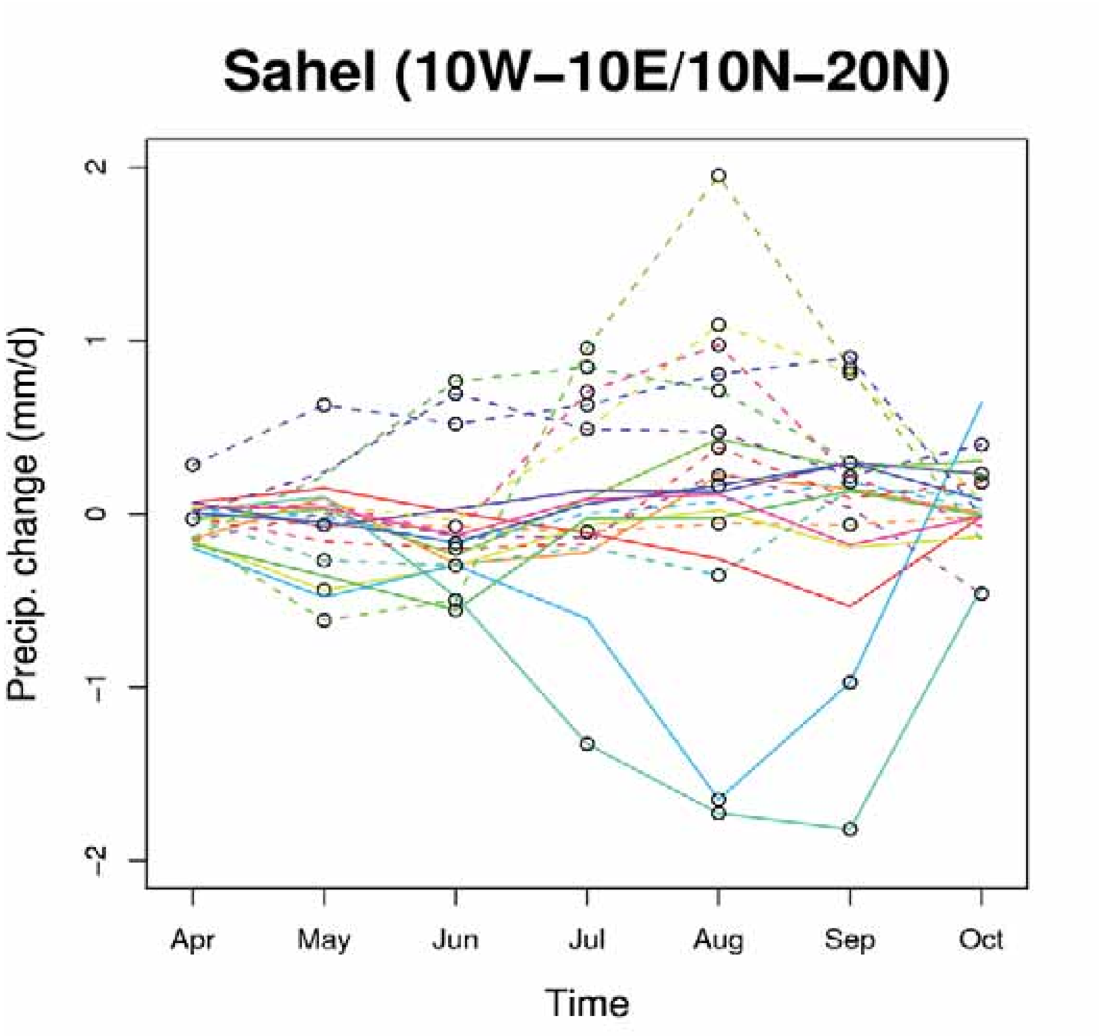


Figure 12 *Predictions of 16 regional climate models, included in the ENSEMBLES project, of daily average rainfall change (on a monthly basis in the rainy season) in West Africa for 2040-50. The average change predicted by all models taken together is close to zero, yet differences of several hundreds of mm over the rainy season between the most extreme models can be observed*

The desk-study of climate model outputs showed that the global and regional climate models yield widely differing results as concerns the future development of rainfall. Increase in rainfall may be just as probable as a decrease, as illustrated in figure 12. If rainfall was to increase, the consequence might be an increase in water level in the wetlands, which could well cause fields in the margin of the seasonally flooded areas to become useless for cassava cultivation, yet it would also increase productivity in the drier areas, where Attieké is the dominating cassava variant. The greatest problem associated with rainfall change may be the greater variability of rainfall and higher maximum rainfall rates, which would cause temporary flooding in low-lying fields without significantly increasing yields in the drier fields, because a greater part will run-off.

These conclusions, drawn from the literature and the ENSEMBLES data base, were supported by Dr. Dr. Daouda Zan Diarra from 'Direction National de la Meteorologie'. It was discussed that the current uncertainty concerning future trends in rainfall makes it very difficult to assess the likely consequences, in general as well as specifically in relation to cassava production, and to make recommendations as concerns climate change adaptation.

16. Discussion and conclusions on feasibility and sustainability of cassava-based bio-ethanol production in the study area

The results reported above paint a picture of a situation for agriculture in the study region characterized by substantially reduced incomes, reductions in the area cultivated and underutilization of labour resources in the dry season, all associated with the decline in cotton production. Farmers are strongly motivated to take up alternative productions which could generate a cash income. Cassava is presently partly taking this role, yet the demand is very seasonal (in the case of bonouma for filling the hunger gap in the north), prices vary greatly over the year and in certain periods fields are not even harvested because there is no demand. Thus a guaranteed year-round market for cassava, even with prices in the low end of what farmers are presently obtaining, is likely to motivate farmers to expand the production substantially. Such an expansion may happen by increasing the cassava area, either by replacing other crops such as maize and rice or by expanding cassava cultivation into former cotton fields presently in fallow, or by increasing cassava yields through greater use of inputs of fertilizers and labour. Both these options are realistic: According to the farmers there is land available for expansion, and this is supported by analysis of satellite images. Large variations in cassava yield may be observed, and factors such as fertilizer input, soil type, water availability and labour input are likely to influence yields. If a market is guaranteed and extension services established there are reasons to believe that average yields can be raised at least a factor of two. Thus we find it realistic that an increase in cassava production of 50-70.000 tons can be achieved within an area of less than a thousand square kilometers in the study region, which would imply low transport costs.

Surveys based on household questionnaires and interviews show that farmers express strong interest in expanding the cassava production and that they intend to achieve this by clearing fallows (mostly 5-10 years old, after cotton production) and/or replacing other crops, such as rice in lowland fields or maize in dryland fields, by cassava. This implies that the effects of such land use change on emission of GHGs must be investigated. It is argued that changes in carbon pools are likely to be the most significant environmental effect of increased cassava production. The effects on carbon storage in vegetation and soils have been thoroughly studied, and it is documented that clearing fallow would result in a loss of carbon in above and below ground vegetation in the order of 8 – 24 Mg C/ha, while changes in soil carbon pools are relatively small and uncertain. With present cassava yields it would take 16-50 years of continuous cassava production for bio-ethanol before the ‘carbon debt’, associated with clearing of fallow, would be ‘repaid’. If other crops were replaced by cassava, no reduction in C storage would take place. If cassava yields were to double, the repayment time would be almost halved. If the land use of ten years ago was taken as the baseline, no reduction in C storage would have taken place, rather it is likely that C storage would have increased. Thus, the more or less arbitrary choice of baseline against which the effects of the cassava expansion is compared has significant consequences for the assessment of the environmental sustainability. Increase in production of the bonouma variant of cassava in wetlands may have an effect on CH_4 emissions, yet analyses of this effect are not finalized. Probably, replacement of rice with cassava will reduce CH_4 emissions. Anyway, our results point in the direction of suggesting that bio-ethanol production should mainly be based on the attieké variant, which is not expected to have significant effects on CH_4 emissions. Higher intensity of cassava production will imply greater use of mineral fertilizers, causing increased emissions of N_2O. The current emissions are relatively insignificant, and we do not expect increased N_2O emissions to play a major role in the overall effect of cassava cultivation in a climate change mitigation context. Other environmental impacts appear to be limited and/or positive, especially if measured relative to a 'cotton baseline', since cotton is not a particularly environmentally benign crop. Overall, the environmental sustainability of cassava-based bio-ethanol production cannot be said to pose major problems.

The economic feasibility of cassava-based bio-ethanol production is very difficult to assess, both because the energy market in Mali (and elsewhere) is heavily politically influenced, and because future world market prices of fossil fuels and competing renewable energy sources are very uncertain. The crude assessment made in this report is based on the assumption that a cassava price of 30-35 CFA per kg would allow a profitable production of bio-ethanol. This assumption may certainly be challenged on a number of grounds, not the least due to the present absence of a market for bio-ethanol in Mali. Any establishment of a bio-ethanol production must go hand in hand with efforts to develop a market. Several interesting options exist, including use of bio-ethanol to replace gasoline (fully or partly) for use in vehicles, for village scale electrification and to replace fuel wood or charcoal in households. The latter is particularly interesting because of its possible positive effects on vegetation carbon pools, bio-diversity and, not the least, human health. If the assumption of a realistic raw material price of 30-35 CFA/kg holds, our survey shows that offering this price to farmers in the study area would trigger a substantial increase in production, provided that the farmers were given a guaranteed demand and price. This price level is substantially lower than that associated with the strongly seasonal production of bonouma, mostly on the wetter lowland soils. Thus, on economic grounds it is evident that the increase of the cassava production will mainly take place on the drier soils, which can be cultivated year-round with the attieké variant, and in particular in periods where there are underutilized labour resources.

As concerns the social impacts of increased cassava-production for bio-ethanol, we argue that the most critical impact is on food security. We have examined the food security impacts locally, regionally and nationally. In the local area it appears that negative impacts on food security are unlikely. In a crisis situation, e.g. in the case of drought, cassava may serve as food reserve, so actually food security may be expected to be improved. At the regional scale it was noted that cassava-based cous-cous, attieké, played a significant role in urban Sikasso, and that this was either produced locally by women's groups on the basis of cassava cultivated in the study area or imported from Cote d'Ivoire. The amounts involved were, however, quite limited, and there is no reason to assume that this value-chain cannot be maintained if a bio-ethanol production is established. The greatest significance, in terms of food security, of cassava production is certainly associated with the large seasonal export of bonouma from the study area to the Segou and Mopti regions during the rainy season (July to September mainly) to fill the 'hunger gap'. The prices obtained by farmers producing bonouma in this season are, however, much higher than the price level assumed to be realistic for bio-ethanol production. This implies that farmers will give priority to producing bonouma for export to Segou and Mopti, and thus we do not expect that there will be any negative effect of bio-ethanol production on the value chain. This further supports the conclusion from the economic analysis that bio-ethanol production should rely mainly on attieké. The main problem with his result is that there may be a decline in supply of attieké to a bio-ethanol production facility in the monsoon season when farmers invest their labour in harvesting and planting bonouma for export to Segou and Mopti. This may require that the bio-ethanol producer has storage facilities for cassava allowing them to stock the raw material for several months. Apart from the importance of cassava for food security in the Segou and Mopti regions, cassava does not play a major role in the food supply of Mali, and establishment of bio-ethanol production is not likely to have major impacts on food security at national level, nor will it contribute significantly to increasing food prices.

In addition to the food security issue, other social effects may result from establishment of a bio-ethanol production. These include impacts on the actors in the current cassava value chains, and in particular on the organization of cassava production and marketing. Presently, producers mainly interact with buyers though local intermediaries, so-called ‘hosts’. In some cases local producers also act as buyers themselves, and use specialized transporters. If a bio-ethanol production facility is established, this existing system may either be used or replaced by an alternative system. One alternative, which is already emerging in some villages, is the establishment of cassava production and marketing cooperatives, which may interact directly with the bio-ethanol production facility. These two systems are already competing, and it is worth noting that this competition may affect the reaction of farmers to the advent of a new, large actor. Farmers have a tradition for being organized in cooperatives in relation to the production of cotton, and it is not unlikely that a similar form of organization will emerge in the case of cassava.

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