Bern University of Applied Sciences
School of Agricultural, Forest
and Food Sciences

Bachelor Thesis

Land use systems in Ghana's Central Region and their potential for REDD+

Zollikofen, 29.11.2013

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Acknowledgement

First of all I would like to thank my advisors Dr. Jürgen Blaser and Dr. Christoph Studer for their support and technical counsel. My gratitude also to Angela Deppeler and Kwame A. Oduro for the organization of my stay and general support during my field assignment. Many thanks to Dr. Victor Agyeman for his encouragement during my stay in Ghana. Special thanks go to Lydia Afriyie for all the hard work on the field, introduction to the Ghanaian culture and friendship. My appreciation for Samson Adonteng for all the assistance on the field and with the communities. I would especially like to thank Forster Amofah and Joseph Amoako for their help with information on essential oil crops and support during my visits at the Portal Plantation and Wellington Baiden for his cooperativeness and patience for my questions. My gratitude to the chief of Bedum and all the farmers in the AOB district for their time and good collaboration. Thanks also go to Emmanuel Appiah-Kubi for providing me with contacts and to all the researchers at FORIG who helped me with technical information: Dr. Stephen Adu-Bredu, Dr. Luke Anglaare, Jonathan Dabo, Dr. Ernest Foli and Dr. Lawrence Damnyag.

Thanks also to Dr. Boateng Kyereh as well as to my fellow students Jacob Amoako and Angella Darko from KNUST. Additional thanks to Oliver Gardi and Christoph Kopp from HAFL for giving me direction. Last but not least I would like to thank Lilith Treindl for correcting my thesis.

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Abbreviations and Acronyms

AGB	Above Ground live dry Biomass
AOB	Asikuma-Odoben-Brakwa
ARC	Agricultural Research Centre
BAU	Business As Usual
BGB	Below Ground live dry Biomass
CRIG	Cocoa Research Institute of Ghana
CTA	Technical Centre for Agriculture and Rural Co-operation
DAFF	Department for Agriculture, Forestry and Fisheries (South Africa)
DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization of the United Nations
FCPF	Forest Carbon Partnership Facility
FIP	Forest Investment Program
FORIG	Forestry Research Institute of Ghana
GHC	Ghanaian Cedi
GLP	Global Land Project
GREL	Ghana Rubber Estates Limited
HDI	Human Development Index
ICRAF	International Centre for Research in Agroforestry (World Agroforestry Centre)
INSEDA	Integrated Sustainable Energy and Ecological Development Association
KNUST	Kwame Nkrumah University of Science and Technology
MLNR	Ministry of Lands and Natural Resources
MOFA	Ministry of Food and Agriculture
MRV	Measurement, Recording and Verification
NTFP	Non-Timber Forest Products
PES	Payment for Ecosystem Services
PET	Potential Evapotranspiration
R-PIN	Readiness Preparation Idea Note
R-PP	Readiness Preparation Proposal
REDD+	Reducing Emissions from Deforestation and Forest Degradation and Enhancing Carbon Stocks
SECO	State Secretariat for Economic Affairs
TNAU	Tamil Nadu Agricultural University
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organization
USD	United States Dollar

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Abstract

FEURER, Mélanie.

Land use systems in Ghana's Central Region and their potential for REDD+

This study has been carried out in the setting of Ghana's efforts to reduce emissions from deforestation and forest degradation and enhance carbon stocks (REDD+). The objective is to analyze traditional land use systems in the Asikuma-Odoben-Brakwa district according to carbon stocks and economic benefits. In addition the potential of introducing essential oil crops as a REDD+ pilot is assessed. In five communities 32 farmers who had cocoa, oil palm, citrus or rubber as a crop were selected. They were interviewed about cultivation practices and the respective farms were measured. On the sample plots tree species were identified and diameter at breast height (DBH) was measured for all trees with a DBH > 3 cm. Then carbon stock was calculated with the DBH and the specific wood density.

The most common land use systems in the district are perennial cash crops in combination with food crops and naturally regenerated trees. Following results were obtained: Rubber stores the highest amount of carbon with 92.6 tC/ha on average. Income reaches 2'228 USD/ha/y. Cocoa integrates by far the highest number of trees (118/ha) and has average stocks of 76.3 tC/ha. Annual income is 525 USD/ha. Citrus stores 61.4 tC/ha on average and has a potential income of 1'125 USD/ha/y. Oil palm stores the smallest amount of carbon (40.5 tC/ha) and also reaches the lowest income (300 USD/ha/y). The proposed land use systems attain following results: Enriched forest stores 126 tC/ha but brings no income; a timber plantation stores 114.6 tC/ha and has an income of 60'000 USD/ha after 25 years; ylang ylang stores 18.9 tC/ha and generates a potential income of 9'462 USD/ha/y; black pepper on gliricidia stores 60.2 tC/ha and brings an income of 11'455 USD/ha/y; nutmeg stores 23.9 tC/ha and has a potential income of 12'630 USD/ha/y; flowers do not store a relevant amount of carbon but bring a potential income of 4'070 USD/ha/y.

All in all, the proposed land use systems have a good potential for REDD+. For smallholder farmers it is recommended to have a diversity of cash crops, valuable trees and food crops. Black pepper is the most suitable essential oil crop for REDD+. It is also preferred by the farmers and should therefore be the first cultivated essential oil crop by smallholders.

Keywords: Ghana, REDD+, Carbon, Agroforestry, Essential oils

1 Introduction

Climate change is one of the major challenges the world is facing in the 21st century. In tropical countries deforestation is the most significant factor for the emission of greenhouse gases. At the same time, these countries are the most vulnerable towards the effects of climate change. In Ghana, the annual deforestation rate is estimated at an average of 2% with an increasing trend between 1990 and 2010 (FAO 2010). Major drivers of deforestation and forest degradation are agricultural expansion, logging, and mining (MLNR 2012).

In this setting several mitigation initiatives have been developed. One of them is REDD+, a strategy to reduce emissions from deforestation and forest degradation and enhance carbon stocks. Agroforestry production systems play a crucial role in this initiative. On the one hand trees in agricultural landscapes serve as carbon sinks while at the same time improving the microclimate. On the other hand they lead to a diversified income for the farmer. This leads to a reduced vulnerability towards climatic changes. Ghana has been preparing for REDD+ since 2008. As part of the preparatory phase, seven pilot projects have been selected. One of these pilots is the production of essential oils in the Asikuma-Odoben-Brakwa (AOB) district in Central Region. The REDDES project, financed by the Swiss State Secretariat for Economic Affairs (SECO), is a preparatory step to support the development and enhancement of climate-smart production systems in the off-reserve area of Ghana. This study is done in the framework of REDDES and aims to assess the existing land use systems in the AOB district as well as the proposed system with the essential oil crops and to rate them according to their potential as carbon sinks and their economic performance. The research questions are the following:

- Which are the existing land use systems in the AOB district?
- What are the carbon stocks and the economic performance of each land use system?
- Which are possible improvements in the land use and what is their impact?
- What is the potential of the essential oils project as a REDD+ pilot?

The hypothesis is that the cultivation of essential oil crops is more profitable for farmers than the existing crops. Carbon stocks are expected to increase if essential oil crops are cultivated in agroforestry production systems. The paper is structured as follows: First, the methods and the research design are described in detail. Second, background information on the study area and REDD+ is given. Third, the existing land use systems in the area are classified. Fourth, the results for each identified production system are presented and discussed. Fifth, possible improvements for the land use in the AOB district are analyzed according to their carbon and economic potential and recommendations for farmers are given. At the end all findings are discussed and a conclusion is drawn for the potential for REDD+.

2 Methodology

2.1 Secondary Data

The literature review was done with documents from three different sources: The REDD+ project and collaborators, the FORIG library as well as the internet.

The climate diagram was based upon data from the program New_LocClim_1.10, which had been developed by the Food and Agriculture Organization of the United Nations (FAO). As reference for the concerned district served the meteorological station in Asikuma.

2.2 Primary Data

2.2.1 Key informant interviews

Semi-structured key informant interviews were held in order to identify the traditional land use systems in the area. Key informants were the chief deputy assistants for cocoa in the region, the district agricultural officer from the Ministry Of Agriculture (MOFA), the assembly man in Bedum as well as several farmers in the AOB district.

2.2.2 Field measurements

For the carbon estimates only the living plant biomass was determined. An exact measurement of all carbon pools (aboveground live biomass, belowground live biomass, dead biomass and soil) was not possible with the resources available for this study. As suggested by White (2011), priority was given to tree biomass, given that this is the biggest carbon pool in agroforestry production systems. However, the most common cropping systems are plantations, so the crop trees were included in the calculated carbon stock. The sample farms were chosen in a convenience sampling design, using the snowball sampling method. In order to make it more representative, the plots were distributed over the major communities (Asikuma, Brakwa, Odoben) in the district. Additional sample plots were chosen in Bedum because of the location of the pilot as well as in Bonsunyina, a small community in the western part of the district close to the district's forest reserves. Each plot was set as convenient as possible inside a farm, which was influenced by the small and irregular farm size. Border rows were left out. For measuring oil palm and citrus plantations, the plot size was 50m x 50m. A smaller plot size would not have been representative due to the wide planting distances. A larger plot size was not possible as most of the plantations are on a small scale basis. For the cocoa and rubber farms the plot size was 20m x 20m because the planting distance is smaller. This plot size allowed to do two replications per farm. For each of the land use systems there were 8 replications altogether. The cocoa system was grouped into three age categories: young (2 - 3 years), young mature (6 - 10 years) and mature (15 - 20 years). In the youngest category not many trees can be found. That is why the research design was adjusted. Measurements were taken on the whole field. Afterwards the field size was determined with a GPS device. For this category, four replications were made. For the Portal Plantation, the plot size was 20m x 20m with two replications for each of the elements (cedrela, ylang ylang, black pepper, nutmeg, conservation area). As for the system with black pepper, only the stems of *Gliricidia sepium* were measured.

On the sample plots existing trees were identified and the diameter at breast height (DBH) was measured for all trees with a minimum DBH of 3 cm. For the oil palm, tree height was measured instead of the DBH. In each plot the number of oil palm trees was counted and five trees were selected for the measurement. The stem height was estimated by holding a stick with the length of 3 m next to the palm tree.

2.2.3 Carbon calculations

Biomass of trees

Total aboveground live dry tree biomass (AGB) was calculated using an allometric equation with the DBH and the wood density. The model of Chave et al. (2005), also suggested in the Field Guide for Forest Biomass and Carbon Estimation from the Woods Hole Research Centre (Walker et al. 2011) was used for this purpose:

$$AGB_{tree} = (\rho*\exp(-1.499+(2.148*\ln(D))+(0.207*\ln(D)^2 - (0.0281*\ln(D)^3))*0.001$$

where p is the wood density in g/cm^3 and D is the diameter at breast height in cm.

Where available, wood density parameters of the different species were taken from the wood library of the Forestry Research Institute of Ghana (FORIG). Several species have not been analyzed according to their wood properties by FORIG. For these species the mean density was calculated from data of the Global Wood Density Database (Zanne et al. 2009). For all species where no data was found (e.g. fruit trees), an average wood density of 0.5 was assumed.

Biomass of oil palm

Concerning palm trees the biomass is more closely related to height than to diameter (Pearson et al. 2005, cited in Kongsager et al. 2012). Observations on the sample plots also indicate that the height does not only depend on the age of the plantation but rather on the management and assumingly the condition of the soil. Therefore it was decided to use an allometric equation with height instead of age. The allometric equation suggested by Khalid et al. (1999) was used for this purpose:

$$W = 725 + (197 * H)$$

where W is the total fresh weight in kg and H is the palm height in m.

The function is based on a palm density of 136 stands/ha (Khalid et al. 1999). Even though the planting distance on the sample plots is a bit shorter, the influence on the biomass of a single tree is assumed to be insignificant and can therefore be ignored. As the equation calculates the fresh weight, a ratio of 0.27 still has to be applied to arrive at the aboveground live dry biomass, as suggested by Konsager et al. (2012).

Total Carbon

Total AGB/ha is calculated by adding the biomass of all single trees in a plot and then multiplying the result by 25 or 4 for the 20m x 20m and the 50m x 50m plot, respectively. As soon as the AGB is known, the below ground biomass (BGB) can be estimated for all farms. For this calculation a root-shoot ratio of 1:4 was used. Cairns et al. (1997) found that the mean ratio for forests is around 0.26. A conversion factor of 0.5 from biomass to C is also recommended by Asare (2013). Both aboveground and belowground biomass were added and divided by 2 to receive the amount of carbon stored in a system.

At the end mean carbon stocks during a lifespan were calculated for each land use. For this purpose an approximate growth curve was drawn for the respective crops. As reference served the data collected on the field and literature of growth rates during different age categories.

All calculations and diagrams were done with Microsoft Excel. Due to the small sample size as well as high variation a statistical analysis was not reasonable.

2.2.4 Questionnaires

For the socio-economic part of the analysis a questionnaire was filled in for each farm. A total of 32 farmers (26 male and 6 female) were interviewed. Out of these, 12 had cocoa, 8 citrus, 8 oil palm and 4 rubber. However, most of the interviewed people had several farmlands of the respective crop as well as other crops. The questions were answered for the farm that was also measured. Remarkable about the characteristics of the sample population (figure 1) is the good education level. Almost all farmers had visited school and most of them even went to junior high or have a higher degree of education. On the other hand, it is assumed that through the sampling method mostly better educated farmers were chosen for the questionnaires, so the 32 farmers should not be considered representative for the entire district.

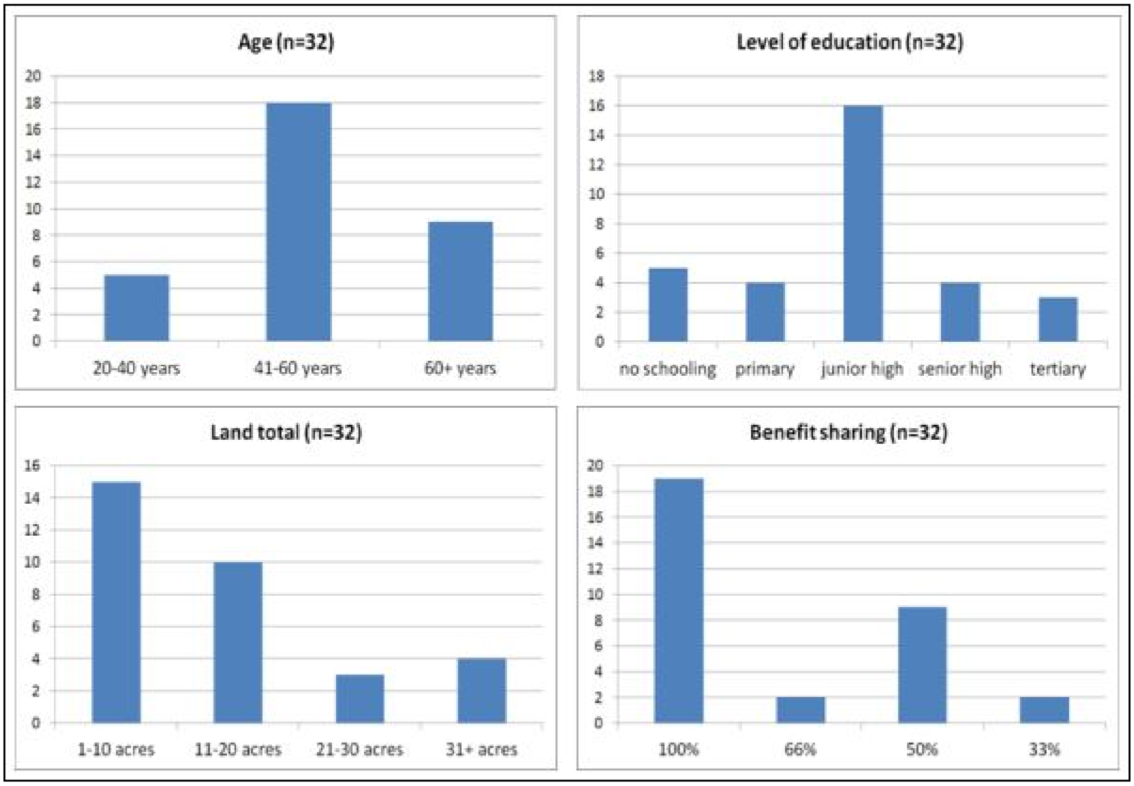

Figure 1 Characteristics of the sample population

2.2.5 Income calculations

The farmers' statements concerning yield, costs and prices of the crops were used to get an overview of the situation in the district. They also served as a reference. To calculate the income of the main crops standard yields and prices were used. Assumptions are depicted in table 1. Costs were not included for comparison. Instead it is assumed that they are similar for the four most common farming systems. The exchange rate as of November 8th 2013 was applied, where 1 Ghanaian Cedi (GHC) is 0.45 United States Dollars (USD) (CoinMill 2013).

Portal Ltd is the company which started with the production of essential oil crops in Bedum. For Portal Ltd different sources were consulted to find out average yields (Nelson and Cannon-Eger 2011; Manner and Elevitch 2006; Anandaraj no date; Lemmens 2008). In addition, the company's estimated production is used as a reference. Oil prices were taken from the two different companies Aqua Oleum and NHR organic oils (Baiden no date). It is assumed that Portal Ltd receives 60% of the end price. If farmers were to produce essential oil crops or flowers and sell them to Portal Ltd, it is assumed that they get 50% off the price that the company receives.

The assumptions for yield and price of each crop are illustrated in table 1.

Table 1 Assumptions for income calculations for each crop

Crop	Yield/ha/y	Oil Yield	Price		Comments	Sources
			GHC	USD		
Cocoa	355 kg	-	3.31/kg	1.48/kg	212 GHC/bag à 64kg	Hainmueller et al. 2011
Oil palm	5.6 t	-	120/t	53.57/t		Factfish 2013; Darko and Klossner 2013
Citrus	10 t	-	250/t	112.5/t		Ofosu-Budu 2013b, personal communication
Rubber	2'931 kg	-	1.68/kg	0.76/kg		GREL 2013; Ofosu-Budu 2013a, personal communication
Cedrela	11.5 m^3	-	463.69/m^3	207/m^3		Lemmens 2008
Ylang ylang	6'000 kg	1%	1178/kg	525.88/kg		Baiden 2009; Manner and Elevitch 2006; Baiden no date
Black pepper	3'930 kg	1.8%	1226/kg	547.30/kg		Nelson and Cannon-Eger 2011; Baiden no date
Nutmeg	1'625 kg	11%	505/kg	225.44/kg		TNAU 2013, Baiden no date
Lemongrass	4'091 kg	0.55%	413/kg	184.37/kg	- yield for intercropping	Chandy no date, Baiden no date
Patchouli	900 kg	2.5%	652/kg	291.06/kg	- yield for intercropping	Chandy no date; Baiden no date
Citronella	10'000 kg	1%	326/kg	145.53	- yield for intercropping	Chandy no date; Baiden no date
Cinnamon	470 kg	-	3360.10/kg	1500/kg	- yield for intercropping	UNIDO and FAO 2005
Flowers	11'970 units	-	1.5/unit	0.2/unit		Forster 2013b, personal communication

3 Background

3.1 Ghana

Country profile

Ghana is a West African country, bordering the Ivory Coast in the West, Burkina Faso in the north and Togo in the east. The country is divided into ten administrative regions, which are further divided into districts. Accra is the capital and Kumasi is the second largest city. Almost all of the area is lowland, with less than 10% being above 300 m (Allotey 2004).

The population reached 25.37 million in 2012 (World Bank 2013).

Ghana belongs to the lower middle income countries and had a GDP of 40.71 billion USD in 2012 (World Bank 2013). With a Human Development Index (HDI) of 0.558 the country is on rank 135 worldwide (UNDP 2013). The main economic activities are oil, agriculture, timber processing and mining (MLNR 2012). Whereas the cultivation of cocoa, cassava, plantain, cocoyam, oil palm and rubber as well as the processing of timber and mining predominate in the high forest zone, the savannah zones are dominated by the cultivation of yam, maize and cassava, plantation forestry, fuel wood production, shea nut collection and processing and mineral exploitation (ibid).

Figure 2 Ecological zones of Ghana (Source: Stanturf et al. 2011)

Ghana can be broadly divided into three climatic zones. Stanturf et al. (2011) divided it further into six ecological zones (figure 2). The humid zone is in the southwest of the country with a natural vegetation of mainly deciduous forest and a small part of evergreen forest. The main agricultural crops in this area are cocoa, cassava, plantain and maize. The transitional zone between the forest and the savannah has a subhumid climate. Here additionally to cocoa fruit like citrus and mango and numerous food crops (yam, cassava, plantain, groundnuts, maize) are produced. Then in northern Ghana as well as in the coastal areas the climate is semiarid and the natural vegetation is savannah. The main agricultural crops are cereals (maize, sorghum, millet) and groundnuts.

Deforestation and Forest Degradation

In Ghana, several types of forest areas are distinguished: Off-reserve areas, protected areas, forest reserves and others such as wetland sites, wildlife sanctuaries or dedicated forests (World Bank 2006). Forest reserves are areas of primary and secondary forests as well as forest plantations, which are under a management plan. Only admitted farms are allowed (World Bank 2006). According to Tufuor (2012), there are a total of 266 forest reserves, out of which 216 occur in the high-forest zone. Deforestation and forest degradation is a major problem in Ghana. Timber contract areas cover both on- and off-reserve forests. FAO (2010) estimated an annual deforestation rate of 2%. As a result there is not much intact forest left outside the permanently protected forests (Tufuor 2012).

At present, Ghana's terrestrial carbon stocks have been estimated to be around 2 Gt, whereby 1.7 Gt of total carbon is stored in above- and below-ground biomass while the rest is in the soils (MLNR 2012). The highest carbon density is found in natural forests of the moist forest zones. There it can reach up to 200 tC/ha (ibid).

3.2 Asikuma-Odoben-Brakwa District

Geographic location and climate

The AOB District is located in the Central Region and is bordering the Eastern Region. Total land area is 88'484 ha, which covers 9% of the Central Region (MOFA 2011).

The district lies in the humid climate zone and has a natural vegetation of moist deciduous forest. The climate is tropical, with average monthly temperatures between 26 and 28°C and a total annual rainfall of estimated 1400 mm. Figure 3 shows that there are two wet seasons. The major cropping period is from February to July. In August a minor cropping season follows, ending in November.

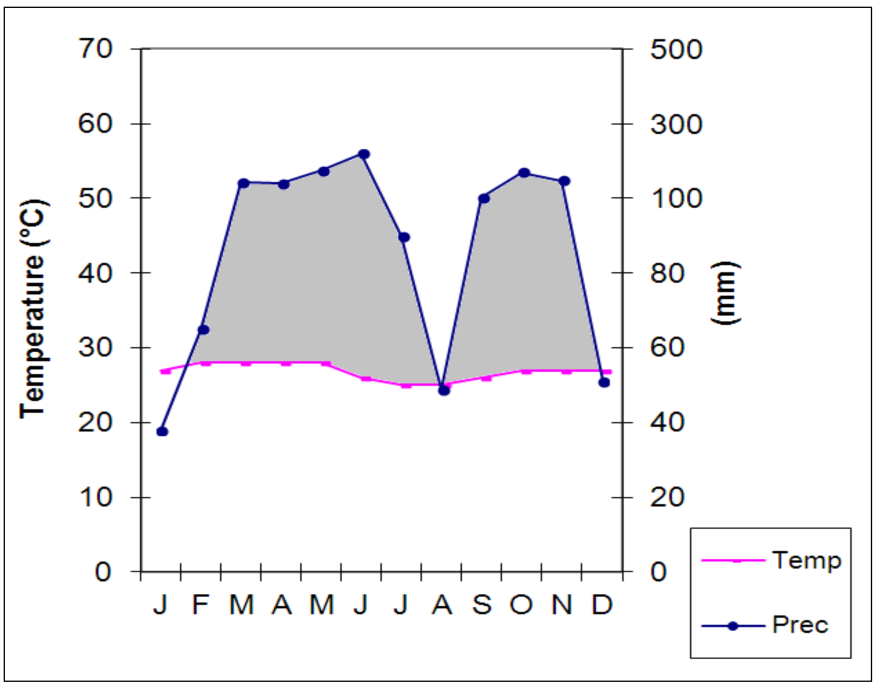

Figure 3 Climate diagram, Asikuma

Demography

In 2000 the population was around 90'000 in the AOB district according to MOFA (2011). Two thirds of the population live in rural areas and more than 70% are engaged in agriculture (MOFA 2011). According to the assembly Mr Mensah 90% of the citizens in Bedum are purely farmers (Mensah 2013, personal communication). Trends show that more people migrate from rural areas to urban centres, mostly outside of the district. As a result, population density inside the district is declining. However, in-migration also takes place mainly through cocoa farmers. It is estimated that 60-70% of the cocoa farmers in the district are migrants (MOFA 2011).

Agriculture and Forestry

There are four forest reserves in the district, covering an area of almost 10'000 ha (MOFA 2011). Off-reserve forest is gradually lost through the conversion to agricultural land use, with cocoa as the main crop.

The agricultural land area is 57'515 ha, out of which 35'394 ha are under cultivation (MOFA 2011). According to different sources (Mensah 2013, personal communication; Entwi and Bernert 2013, personal communication), the land in the district is very fertile and suitable for several different crops. Agriculture is purely rainfed, as is the case in all of Ghana. Mechanization is in general very low.

Existing land tenure systems in the AOB district are leaseholds and sharecropping. Leaseholds are usually given for 30 or 99 years. As a rule, sharecropping agreements are made for the duration of a plantation, i.e. 20 to 60 years. Tenants either receive half (abunu) or one third (abusa) of the harvest, while the land owner receives the rest.

3.3 REDD+

3.3.1 Definition

Climate change mitigation is the overall goal behind REDD+. The assumption is that CO_2-emissions can be mitigated through the conservation or planting of trees which sequester carbon during their lifespan. The Forest Carbon Partnership Facility (FCPF 2013) defines REDD+ as "countries' efforts to reduce emissions from deforestation and forest degradation, and foster conservation, sustainable management of forests, and enhancement of forest carbon stocks." The objective of REDD+ is to reverse the trend of forest conversion to other land uses, mainly agriculture, and to encourage forest conservation in developing countries by rewarding participating individuals, communities and governments with carbon finance originating from developed countries (Mantlana 2011). It is thus a form of payment for ecosystem services (PES). These payments will come in the form of incentives for the communities to reduce the rate of forest conversion and degradation and to change land use management (Asare 2013).

The emphasis is not only on climate change mitigation actions but also on adaptation strategies for the forest communities and the farmers. Climate change issues are linked with pro-poor development in tropical countries. It is seen as a "win-win approach to reducing deforestation while also alleviating poverty of vulnerable communities" (Mbow et al. 2012).

3.3.2 Off-reserve REDD and the role of agroforestry

According to Mbow et al. (2012), there are four basic types of forest carbon offset projects: Afforestation/reforestation; improved forest management; reduced emissions from deforestation and forest degradation; agroforestry. For agroforestry project types CO_2 reductions in the atmosphere can be achieved either through additional carbon sequestration in vegetation and soil or through avoided emissions resulting from a change in agricultural practices (Mbow et al. 2012).

Figure 4 shows the effect of land use change on the carbon stocks. The introduction of agroforestry practices is an opportunity to increase the carbon storage on land which has already been converted to agriculture. Off-reserve REDD therefore focuses on the restoration of degraded forest lands.

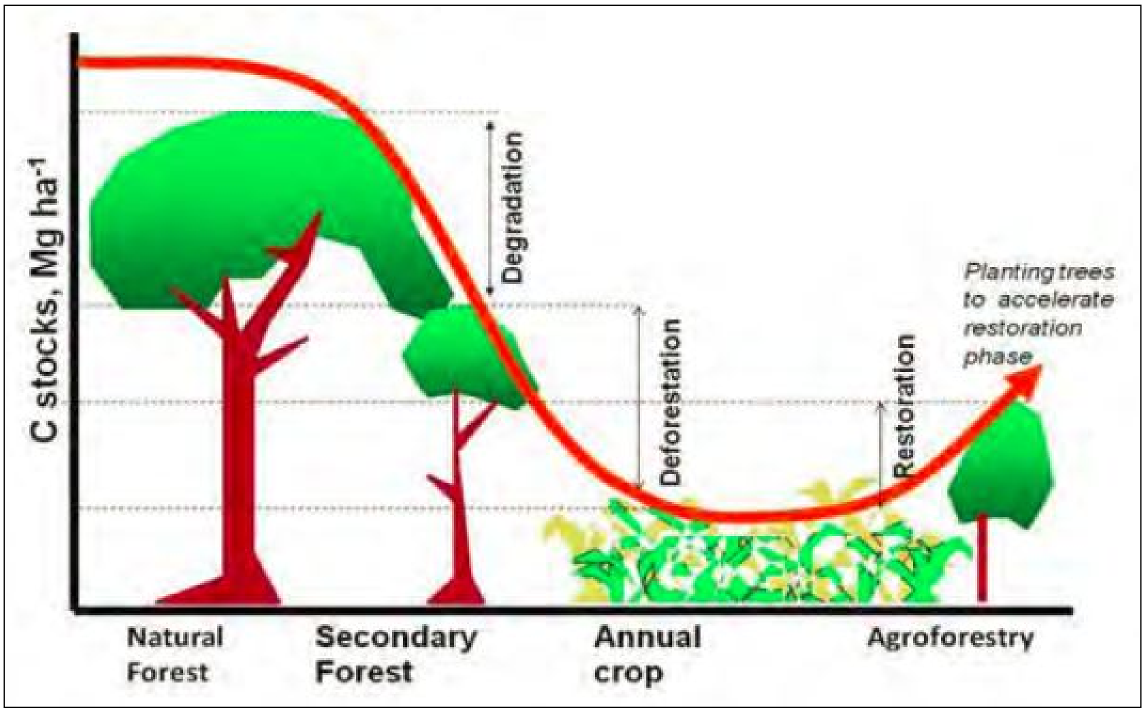

Figure 4 The influence of land use systems on carbon stocks over time (Source: White 2011)

On the other hand tree-based farming systems can also reduce forest degradation by supplying the household with firewood and other non-timber forest products (NTFP), resulting in receding pressure on nearby forests. In Ghana, off-reserve areas can be under a variety of land use types, i.e. natural forest, agricultural land or fallow land. Off-reserve land is accessible to the communities and can be purchased by anyone who has the financial means.

3.3.3 REDD+ in Ghana

Ghana has engaged in the REDD process since Bali 2007 (Kwakye 2011). The first official steps were in 2008, when the FCPF approved of the country's REDD+ Readiness Preparation Idea Note (R-PIN). Afterwards the Readiness Preparation Proposal (R-PP) was submitted to FCPF and approved in 2010. An FCPF Readiness Grant of 3.6 Mio USD was signed (Kwakye 2011) and in 2012 the REDD+ Readiness Programme was officially started. The framework for the programme implementation is divided in three phases. Phase 1 started in 2010. In phase 1 the national REDD+ strategy, policies and measures are defined. Capacity building is also taking place in this phase. In Phase 2 (2012 - 2013) the REDD+ strategy and the policies and measures are established. Further capacity building, technology development and transfer as well as demonstration activities and pilots are implemented. Phase 3 is starting in 2013 with the implementation of specific actions. In this phase full measurement, reporting and verification (MRV) is required.

3.4 Business as usual (BAU)

In the AOB district the primary driver of deforestation is the expansion of smallholder agriculture. Secondary drivers are population pressure, low agricultural productivity and the promotion of plantation crops which cannot accommodate food crops after canopy closure.

The BAU scenario for the AOB district is that all of the off-reserve land is gradually converted to agricultural land uses. Most of the forest land has been cleared already in order to cultivate cocoa or other cash crops. This means that most of the land available for purchase are farms that had been abandoned after their productive cycle. Seeing that farmers try to expand their land in order to plant food crops as well as increase the production of economic crops, all of the land will be used for agricultural purposes in the future. The result is that the highest share of land will be occupied by tree crop plantations whereas a small part of the area will be set aside for the cultivation of food crops. In this scenario, only few forest trees would be left on the farmland.

In a separate study the carbon stocks on abandoned farms, secondary forests as well as sacred groves in the AOB district were assessed. Amoako (2013b) found average carbon stocks of 66.6 t/ha, whereas big differences between the types of vegetation were observed. By far the highest amount of carbon is stored in sacred groves (206.9 t/ha). Degraded secondary forest has only 36.9 tC/ha stored on average. From the abandoned farms, cocoa stored 52.4 tC/ha, oil palm 32.3 tC/ha and food crops only 4.3 tC/ha.

Due to the absence of a clear forest frontier and the composition of the landscape with interspersed patches of agriculture or agroforestry with only few remnants of natural forest, a strategy to increase carbon stocks and biodiversity on the existing farmland needs to be adopted (Kumar and Nair 2011). Complex agroforests are the most promising alternative. In a REDD+ perspective the remaining degraded forestland should be restored.

4 Results and Discussion

4.1 Classification of traditional land use systems

The most common land use systems in the AOB district are plantation crops in combination with food crops (figure 5). The major plantation crops are cocoa (*Theobroma cacao*), oil palm (*Elaeis guineense*), citrus (*Citrus sinensis*), rubber (*Hevea brasiliensis*), teak (*Tectona grandis*) and coconut (*Cocos nucifera*) in this order (Agyarko 2013, personal communication). Cassava (*Manihot esculenta*), plantain (*Musa eumusa*), maize (*Zea mays*) and cocoyam (*Colocasia esculenta*) are frequently cultivated food crops during the first few years of establishment.

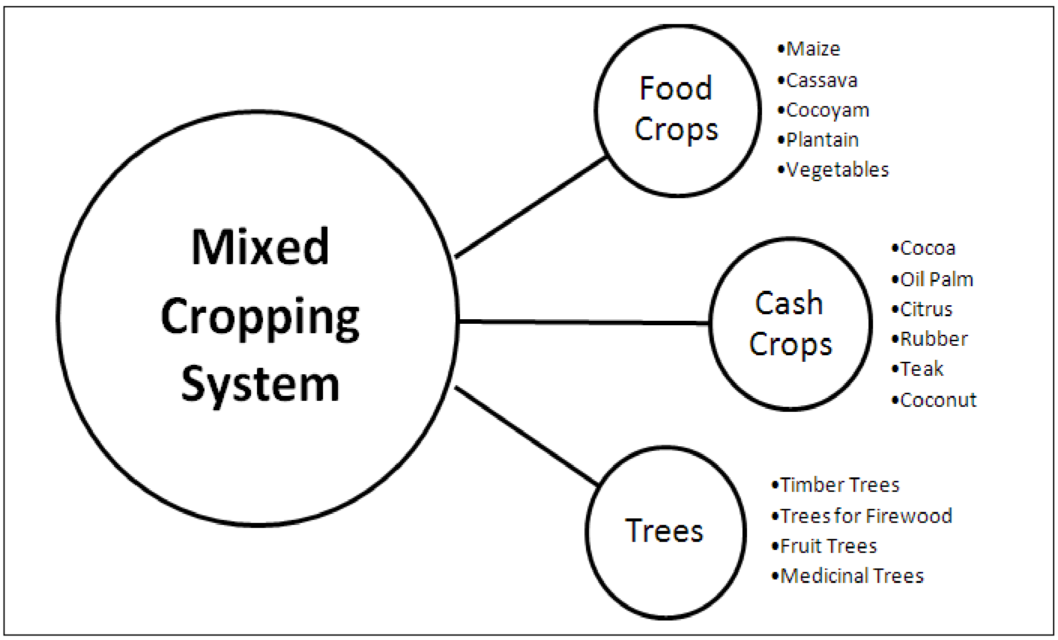

Figure 5 Mixed Cropping Systems in the AOB district

The majority of farmers in the AOB district are small-scale farmers with an average landholding of 6.7 ha and a range of 2.4 - 30 ha.

Before establishing new plantations, secondary forest or fallow land is cleared. Some of the farmers leave the organic matter to decompose but the majority burns the debris in order to facilitate early land cultivation. In cases where organic matter is left on the field farmers need to wait for at least four months to start seeding (Entwi and Bernert 2013, personal communication).

A big difference between the plantation crops concerning the presence of timber trees can be observed. In cocoa plantations a significantly higher amount of timber and fruit trees was found compared to all of the other cropping systems. However, all of the plantations were very heterogeneous concerning the planting distance of the tree crops and the number of large trees integrated in the system.

Usually a household owns several farms, often with different types of plantation crops. Labour requirements do not interfere much between the two most common crops, cocoa and oil palm. While the highest labour requirements for cocoa are between September and March, most of the labour for oil palm is needed between February and July (Amoah et al. 1995). Almost every farmer has at least one cocoa farm because of the stable market and fixed price. The plantations usually differ in age, so that a household is able to plant food crops on at least one of the farms each year. Yam on the other hand is commonly grown on small plots separate from the other crops. A minority cultivates all food crops separately. Trends in show that presently less land is used for the purpose of growing food crops than in the past. Many farmers see this as a potential problem in the future. They observed an increase of food prices in the last few years.

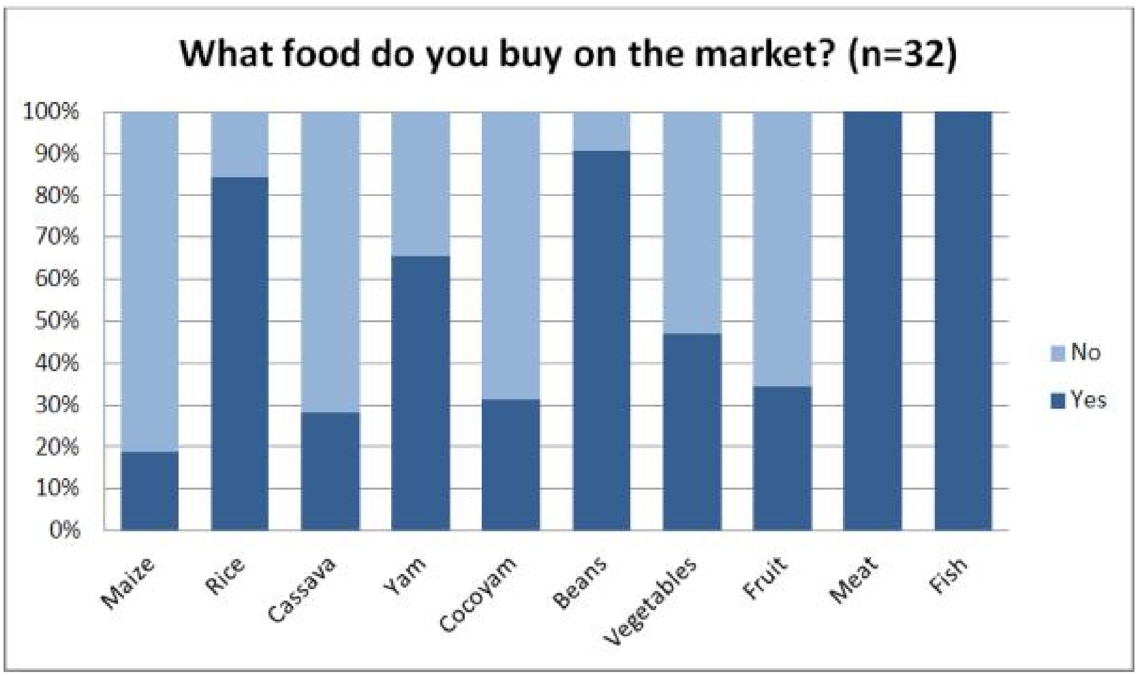

Figure 6 Percentage of farmers buying different foodstuffs on the market

Figure 6 indicates that mainly staple food crops which do not grow well in the AOB district (rice, yam and beans) are bought on the market. Additionally, every fourth of the interviewed farmers has to buy cassava and every fifth purchases maize on the market. These two are the major crops associated with tree crops in the first years of the plantation. Vegetables (including cocoyam leaves) and fruit are only bought from time to time. Meat or fish is an important part of the diet in Ghana, but in most cases in the AOB district the animals are not raised by the consuming households themselves. Even though several farmers keep livestock (mainly goats, sheep or chicken), they usually sell the live animals and in turn buy meat and fish for consumption on the market. Only on special occasions an own animal is slaughtered.

Apart from the mixed plantation food crops system there is also small-scale vegetable production with okra, garden eggs and tomatoes taking place in the district. A few farmers cultivate sugarcane as a cash crop or rice where the conditions are suitable.

In this study only the four most widespread traditional cropping systems are analyzed in detail: Cocoa, oil palm, citrus and rubber.

4.2 Trees on farms

As indicated by several studies concerning cocoa (Hirsbrunner 2012; Wade et al. 2010; Asase et al. 2008) the most significant amount of carbon stored in mixed systems derives from large trees such as old timber trees.

Most farmers keep some trees on their farms irrespective of the land use system. The number of trees per hectare however differs between the cropping systems. From the mature sample farms, cocoa plantations integrate by far the highest number of timber and fruit trees with an average of 118 trees/ha. The share of large trees with a DBH of 30 cm and more is with 22% also the highest for cocoa. Citrus plantations rank second with 43 trees/ha (7% large trees). Rubber and oil palm plantations integrate 25 and 17 trees/ha respectively. The share of large trees is 12% for rubber and 6% for oil palm. The majority of trees are naturally regenerated, since tree planting is not very common. Nevertheless, if cocoa farmers are provided with seedlings they are willing to plant them for shade. The preferred species for planting are *Milicia excelsa, Terminalia superba* and *Terminalia ivorensis*. They are characterized by their fast growth rate as well as their value in the timber market. These are also the species that are found the most desirable by the Cocoa Research Institute of Ghana (CRIG 2010).

In all sample plots a total of 48 different species were found. Because they were not planted it shows that farmers are aware of the uses of different indigenous species. Even though the diversity is high, there are a few dominant tree species. By far the most popular is *Morinda lucida*, followed by *Carica papaya* and *Rauvolfia vomitoria*. Table 2 lists the most common species as well as their prevalence in the sample plots and their uses. A table with all the identified species can be found in the annex.

Table 2 Top 10 tree species on plantation farms in the AOB district of Ghana

	Local name	Scientific name	Number of trees per DBH class				Use					
			<10	10-29	30+	Total	T	R	F	C	M	O
1	Konkroma	*Morinda lucida*	39	38	3	80	X	X	X			
2	Pawpaw	*Carica papaya*	26	16	-	42				X	X	
3	Kakapenpen	*Rauvolfia vomitoria*	18	11	-	29		X	X		X	
4	Badua	*Phyllanthus muellerianus*	10	8	-	18		X	X		X	
5	Foto	*Glyphea brevis*	6	10	1	17			X			X
6	Sese	*Holarrhena floribunda*	12	5	-	17		X	X			
7	Nyankyerenee	*Ficus exasperata*	9	2	4	15			X			X
8	Ofram	*Terminalia superba*	2	7	-	9		X	X			X
9	Okoro	*Albizia glaberrima*	2	4	2	8		X	X			
10	Odum	*Milicia excelsa*	3	4	1	8	X	X	X			

Legend: T: timber (export) R: roofing/furniture (household) F: firewood C: consumption M: medicine O: other

Some of the trees can be used as timber for export. But because these trees are owned by the government, most of the farmers fell them before they reach timber size. Then they are used locally for roofing or furniture. Trees on farms are an important source of firewood for the household as well as the whole community. Over 90% of the interviewed farmers indicated forest trees on their farms as their primary source of fuelwood, in addition to the pruned branches of the plantation crops. Other uses for trees include fodder for livestock, soap, incense or fibre.

4.3 Carbon stocks and economic performance in different systems

4.3.1 Cocoa plantation

Biophysical characteristics

The studied cocoa farms range between 2 and 8 acres, with an average size of 3.5 acres. As of late, Hybrid varieties are predominant, even though some farmers still have Amazonia, often mixed with Hybrids. In the first two to four years food crops are dominating, while cocoa is already planted. Maize is always the first crop and can be harvested after four months. In good years two crops of maize can be cultivated, one in the major rainy season and another one in the minor rainy season. Cocoyam is typically not planted but just grows naturally on the fields. At this stage, plantain as well as cassava provide temporary shade. The advantages of already having some mature trees at this stage is that they can serve as windbreaks for the plantain, which is susceptible to wind (Rehm and Espic 1991). Then after a few years, as the shade trees and cocoa trees grow and compete for light, the cultivation of food crops has to be stopped. Due to the diverse crops (table 3) in this system, income generation is guaranteed each subsequent year.

CRIG suggests a planting pattern of 3m x 3m, leading to a number of 1'111 cocoa plants (CRIG 2010). In reality planting distance varies highly between farmers but also inside one farm. No clear pattern can be identified. What is evident is that the average farm has a more narrow planting distance, leading to a number of 1'429 cocoa trees on a hectare. In all cocoa farms shade trees are present (on average 118 trees/ha). However farmers typically do not plant them but just let the valuable species grow tall after they naturally regenerated. CRIG (2010) on the other hand recommends leaving 35 - 45 trees/ha while clearing the forest and eventually thinning out to 15 - 18 trees/ha.

Table 3 Cropping pattern in a cocoa agroforestry system

Year	1	2	3	4	5	6	7	8	9	10-30	30+
Maize	X										
Cassava	O	X	X								
Plantain	O	X	X	X							
Cocoyam	O	X	X	X							
Cocoa	O	O	O	X	X	X	X	X	X	X	
Fruit trees	O	O	X	X	X	X	X	X	X	X	
Timber trees	O	O	O	O	O	O	O	O	O	O	X

Legend: O: crop is present X: harvest

In general, the lifespan of a cocoa plantation can vary greatly depending on the climate, the condition of the soil and especially on the management. Shaded cocoa trees can produce for 60-100 years under optimal soil and rainfall conditions (Ruf and Zadi 1998, cited in Hoogendijk 2012). In Ghana on the other hand, cocoa farms are usually abandoned or re-planted after about 30 years, after productivity started declining. This was confirmed by the interviewed cocoa farmers. They stress however that the lifespan is highly related to the management practices (use of inputs, weeding, pruning). Cocoa farms with 20 years and more were difficult to find in the district, because the old farms were abandoned due to low yield and replaced with new farms of hybrid varieties. In a study on cocoa agroforestry systems in the Ashanti Region of Ghana, Darko-Obiri et al. (2007) found that for hybrid cocoa the optimum economic rotation is between 18 and 29 years, whereas it is much longer for the old varieties. This leads to the assumption that the short rotation in the district is related to the introduction of hybrid varieties.

Carbon stocks

The sample farms are very heterogeneous. Figure 7 shows that the data points are scattered widely. Even within the same age categories the distribution is irregular. This is especially the case when shade trees are included, which indicates that the quantity and size of shade trees varies greatly from farm to farm. Nevertheless, over the years a growth trend of carbon stocks can be observed. This leads to the assumption that at least some of the shade trees are allowed to grow to timber size. The older the plantation gets the bigger is the share of the carbon in the large trees compared to the cocoa trees. After 6 years 35% of total carbon is stored in shade trees, while after 20 years it increases to 71%. The carbon stored in the cocoa trees alone is not much amplified over the years once the plantation is in full production. The same observation was made by Hirsbrunner (2012). The main cause is the regular pruning and felling of excessive cocoa trees as a management practice to reduce the incidence of diseases.

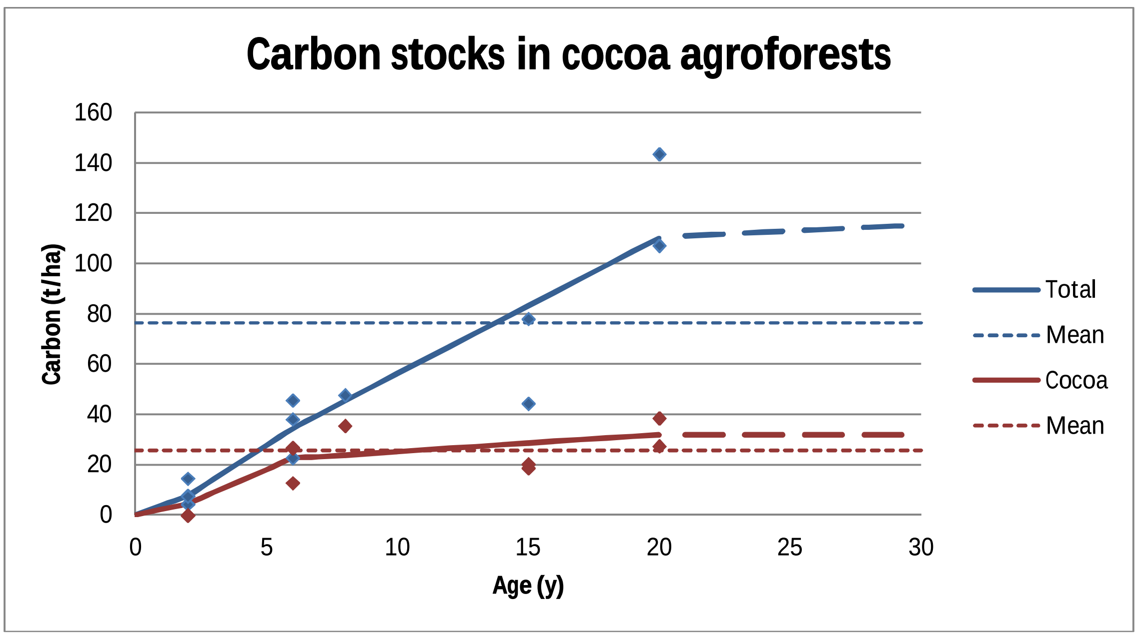

Figure 7 Carbon stocks in cocoa plantations

The mean carbon stock over a lifespan of 30 years is 76.3 t/ha. Out of this, 25.8 t derive from cocoa trees, while the rest is stored in shade trees. With a prolonged use of the plantation the potential for carbon storage could be exploited even further.

The results correspond well with previous carbon estimations made in Ghana. Hirsbrunner (2012) found total carbon stocks of 94.85 t/ha and 71.14 t/ha for plantations of Amazonia and Hybrid, respectively. Konsager et al. (2012) estimated a total of 65 tC/ ha aboveground in a 21-year-old cocoa plantation at the Agricultural Research Centre (ARC) in Kade, Eastern

Region. Adding belowground carbon, the total would be 81 t. Isaac et al. (2007) found 20.55 tC/ha aboveground for 8-year-old cocoa under *Milicia excelsa*.

Economic performance

Generally cocoa yields in Ghana are very low compared to other countries. Hainmueller et al. (2011) found a median yield of 355 kg/ha, which was confirmed by the farmers in the AOB district. With a price of 212 GHC per bag of 64 kg, which was paid to them in 2012, the annual income is 1176 GHC (529 USD).

Support from the government, a sure market and stable prices are the main reasons for farmers to favour cocoa production over other cash crops. For small-scale farmers this is a risk reduction strategy. Other motivations are the extension services provided by the Cocoa Board or the cocoa farmers' association which has been formed in the district.

Potential improvements

For cocoa agroforestry systems there are basically two strategies for improvement, which are not mutually exclusive: improving carbon stocks and raising productivity.

The farms have a high potential to improve carbon stocks through shade management. As mentioned before, cocoa trees alone do not contribute much to the carbon stocks. Carbon stock enhancement therefore has to come from large trees. If more shade is provided, the planting distance of the cocoa trees needs to be adjusted in order to avoid too much humidity and therefore high disease pressure. Possibilities are the retention of valuable timber species or the systematic planting of other perennials such as fruit trees. Fruit trees have several advantages over timber trees: A much earlier income opportunity is possible, if consumed in the household fruit can help improve the family's diet and the produce can be sold on local markets. In case the essential oils project is implemented in Bedum, tourism would also be increasing. As a result the demand for local fresh fruit will rise and ensure a higher price for the farmers. Possible local types are mango, papaya, citrus or guave. Exotic fruit species could also be introduced. Ghanaian cocoa farmers appear to be very interested and willing to try them out provided the seedlings are available (Deppeler and Feurer 2013). However, more research has to be done on the effect of those trees on cocoa. To achieve a higher shade level in the farms, other issues like tree tenure and capacity building in tree management need to be addressed simultaneously.

Cocoa farms in the AOB district have considerably low yields. This means that the potential for improvement is very high. With a strategy to overcome this gap, the income per hectare could be raised significantly. The high number of cocoa trees on the farms are a possible explanation for the low yield. With such a close spacing between the crop trees humidity in the plantations is very high. As a result, disease pressure and the prevalence of fungi are amplified. It seems that humidity is primarily supported by the high density of cocoa trees and less so by the few shade trees present in the system. As a measure to avoid this farmers should reduce planting distances and thereby improve the yield of the remaining trees. This procedure could at the same time be an incentive to leave more of the large trees on the land, resulting in enhanced carbon sequestration. An additional benefit of healthier cocoa plants is the prolonged lifespan. This is particularly for tenant farmers an incentive, since their arrangement with the land owners lasts for as long as the perennial crop is productive. When land is getting scarce and land prices are increasing it can be assumed that achieving a long economic lifespan will become even more important.

Major constraints to achieving higher yields are low financial means for inputs as well as the lack of communication between researchers and extension agents.

Potential for REDD+

The results highlight the importance of shade trees for carbon sequestration.

At the moment cocoa farms are acceptable but not very sustainable with a lifespan of 30 years. On the other hand, the potential is extremely high. With the integration of more large trees this land use system is a promising alternative for REDD+. The focus needs to be on complex agroforestry systems, where both carbon stocks and productivity can be increased in the long term. Additional trees would also have the potential to prolong the lifespan of cocoa plantations. These improvements require a close collaboration between researchers, extension services and farmers.

4.3.2 Oil palm plantation

Biophysical characteristics

The entire oil palm production in the AOB district is carried out by smallholders. Not only the cultivation but also the processing is done locally on a small-scale basis. None of the bigger processing facilities in Ghana are within reach of the district. Farm sizes of the interviewed farmers vary between 2 and 4 acres, with one exception of 17 acres.

Oil palm is often cultivated in swampy areas or on degraded lands where other crops do not grow well. In these cases, food crops are not integrated in the farming system. Under normal conditions, according to Nuertey (2000, cited in Nuertey et al. 2009) smallholders cultivate food and cash crops in the initial three years of the oil palm establishment. In the AOB district, where oil palm is grown on fertile land, maize, cassava, plantain and cocoyam are cultivated for up to five years (table 4). In addition, on the sample plots it was observed that pineapple is often found scattered on oil palm farms and irrespective of the age of the plantation. Pineapple is suitable for intercropping with oil palm for two reasons: It prefers semishadowed conditions and it grows well even on degraded soils (Naturland 2001), where oil palm is usually cultivated.

Only few trees are integrated with oil palm. Since no trees are planted just naturally regenerated trees are found on the farms. It can be assumed that indigenous trees do not grow well on degraded soils.

Table 4 Cropping pattern in an oil palm plantation

Year	1	2	3	4	5	6	7	8	9	10	11-20
Maize	X										
Cassava	O	X	X								
Plantain	O	X	X								
Cocoyam	O	X	X								
Pineapple	(O)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)
Oil palm	O	O	O	O	X	X	X	X	X	X	X

Legend: O: crop is present X: harvest

According to Khalid et al. (1999), oil palm plantations typically stand for about 25 - 30 years. The main reason why the plantation is abandoned afterwards is that palm height is making the harvest increasingly difficult. Most of the interviewed farmers in the AOB district mention an economic lifespan of 15 - 20 years with an average of 18 years. Only one farmer suggested he would use the plantation for more than 20 years. Afterwards the palms are either abandoned or felled in order to start a new plantation.

All in all the sample farms are in a rather neglected state. Weeding and other management practices such as pruning are not done on a regular basis. Farmers use oil palm only as a small extra income.

Carbon stocks

Like most perennial crops, oil palm sequesters carbon mainly in the first years of development. After reaching maturity the carbon stocks remain at a level of around 50 t/ha. Irrespective of age, all sample farms had between 39 - 67 t stored. Figure 8 shows that with a lifespan of 20 years, the mean carbon stock is approximately 40.5 t/ha. Only 3% of the carbon is stored in large trees integrated in the oil palm plantation.

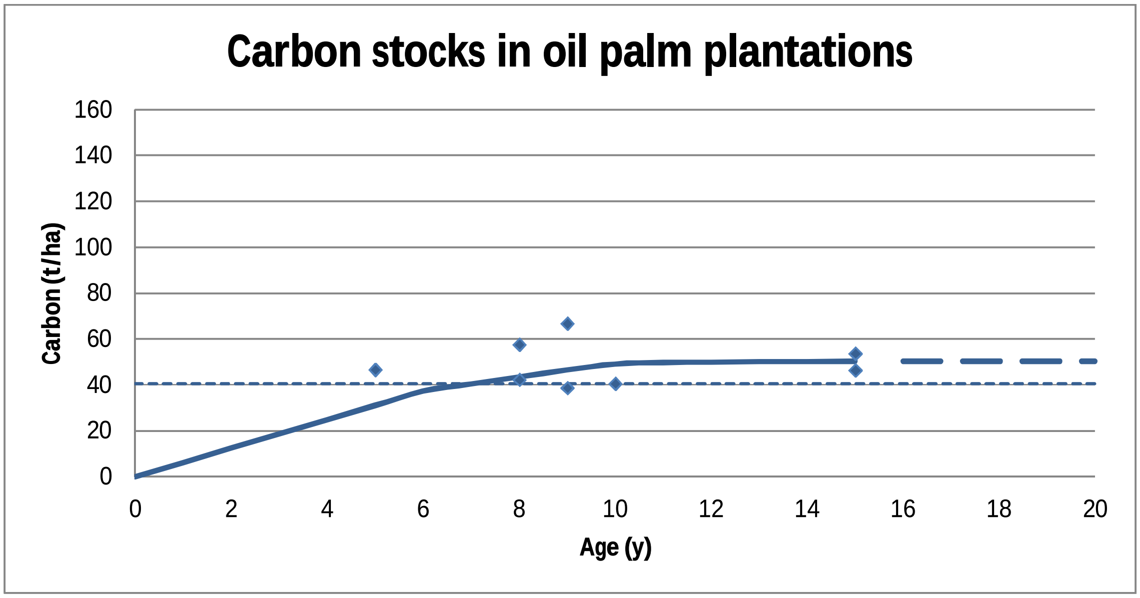

Figure 8 Carbon stocks in oil palm plantations

Results from different studies on the amount of carbon stored in oil palm plantations vary greatly and comparisons are therefore difficult. The results of this study are higher compared to those obtained by Konsager et al. (2012) at the ARC in Kade. They found aboveground carbon stocks of 21.7 t/ha for a 7-year-old plantation and 28 t/ha for a 16-year-old plantation. For the most part, these differences can be explained by the higher palm density on smallholder farms. The average density was 178 palms/ha, whereas Konsager et al. (2012) noted 144 palms/ha at the research station.

Economic performance

The fresh fruit bunches of the oil palm are locally processed into palm oil and palm kernel oil. Often the fruit is directly consumed in the farming households as part of a local dish. Because of this oil palm does not play a significant part in the livelihoods of the farmers. If all of the harvest was sold on the market an annual income of 302 USD/ha could be earned. However, it needs to be considered that there are little costs involved in the production. Also, if oil palm is cultivated on land not suitable for other crops it is still a reasonable gain for the farming household.

Potential improvements

Enhancing productivity is the best way to improve oil palm cultivation in the AOB district. Carbon stocks on the other hand could only be increased by integrating more timber trees, which seems unlikely. Weeds are the main challenge observed in smallholder oil palm plantations. Several strategies could be pursued to suppress their growth. One possibility is to sow a (leguminous) cover crop between the oil palm (Nuertey et al. 2009). This would enhance soil fertility while at the same time suppress the growth of weeds. Providing farmers with technical knowledge on cover crops and their management would be necessary. Another possibility is to introduce small ruminants in this system. Sheep rearing under tree crop plantations is already practiced by some of the farmers and on research stations with a stocking rate between 3 and 18 sheep/ha (Fianu et al. no date). For this purpose grass or herb species can be sown under the oil palm and serve as fodder for the sheep. Advantages are additional income generation, diversification of livelihoods, weed control and manure as natural fertilizer. Constraints for adoption by the farmers are among others the absence of fences and therefore damages to arable crops, lack of technical knowhow in livestock rearing, lack of credit and limited access to breeding stock (Fianu et al. no date). A third option to improve the yields is the use of mineral fertilizer, as oil palm needs a high amount of nutrients to produce well (Nair 1980).

In any case, the importance of oil palm for the farmers still needs to be further assessed. Seeing that oil palm is not a commercial crop in the district and typically grown on marginal soils, it seems that improving cultivation practices is not the first priority of the farmers. As long as oil palm is not sold on the market, the incentive to increase production is low. Also, intensification is difficult on such a small scale.

Potential for REDD+

Oil palm is of little significance for REDD+ because of the low carbon sequestration and short life cycle. In the AOB district the production is not yet commercialized, which is also a reason for the low income possibilities. Therefore the emphasis should be laid on other crops. Nevertheless, oil palm will continue to be important for smallholders due to its adaptability to less fertile soils as well as its use in the local diet.

4.3.3 Citrus plantation

Biophysical characteristics

In the AOB district two *Citrus spp* are cultivated, usually on the same field: *Citrus sinensis* (sweet orange) and *Citrus nobilis* (tangerine). The prevalence of sweet orange however is much higher. The interviewed farmers' plantation size is between 1 - 4 acres except for one farmer who had 11 acres of citrus.

In the first few years of plantation establishment the common food crops are cultivated, as illustrated in table 5. A few farmers had plantain even in later stages with mature citrus, depending on the planting distance of the tree crops. Between the citrus farmers, the number of years the food crops stay on the field varies to a great extent.

Table 5 Cropping pattern in a citrus plantation

Year	1	2	3	4	5	6	7	8	9	10-40	40-60
Maize	X										
Cocoyam	O	X	X	X							
Cassava	O	X	X	X	(X)						
Plantain	O	X	X	X	(X)	(X)					
Citrus	O	O	O	O	O	X	X	X	X	X	(X)

Legend: O: crop is present X: harvest

All of the interviewed Citrus farmers stated that trees negatively affect the yield of the plantation. Even though shade can be tolerated, maximum flowering occurs when citrus is grown in full sun (Zekri 2011). Because of this not many timber trees are found on citrus farms. In any case, they are not kept intentionally for a specific purpose. Most trees found on the sample plots were on farms that were not actively managed. In general the majority of the citrus farms have been neglected and are infested with weeds.

Even though some farmers said that a citrus plantation can produce for up to 100 years, most trees have an economic lifespan of around 30 years (ICRAF no date). In the AOB district plantations are normally kept for around 60 years.

After the citrus' economic lifespan the wood can still be used for planes (Irvine 1961). It is not known however whether it is actually used in the district.

Carbon stocks

While tree growth rates are high from the second year onwards and then slow down after fruiting becomes regular, typical tree size is reached after about 14 years (Manner et al. 2006). This prediction in relation with data obtained in the AOB district suggest that after around 20 years a maximum of 71.5 tC are stored in the plantation. Due to the long economic lifespan of 60 years, mean carbon stocks are 61.4 t/ha (figure 9). There are some large trees found in the sample farms, forming part of the biomass. In fact 12% of total carbon is stored in trees other than citrus. The percentage is higher than in oil palm or rubber plantations, but significantly lower than in cocoa farms.

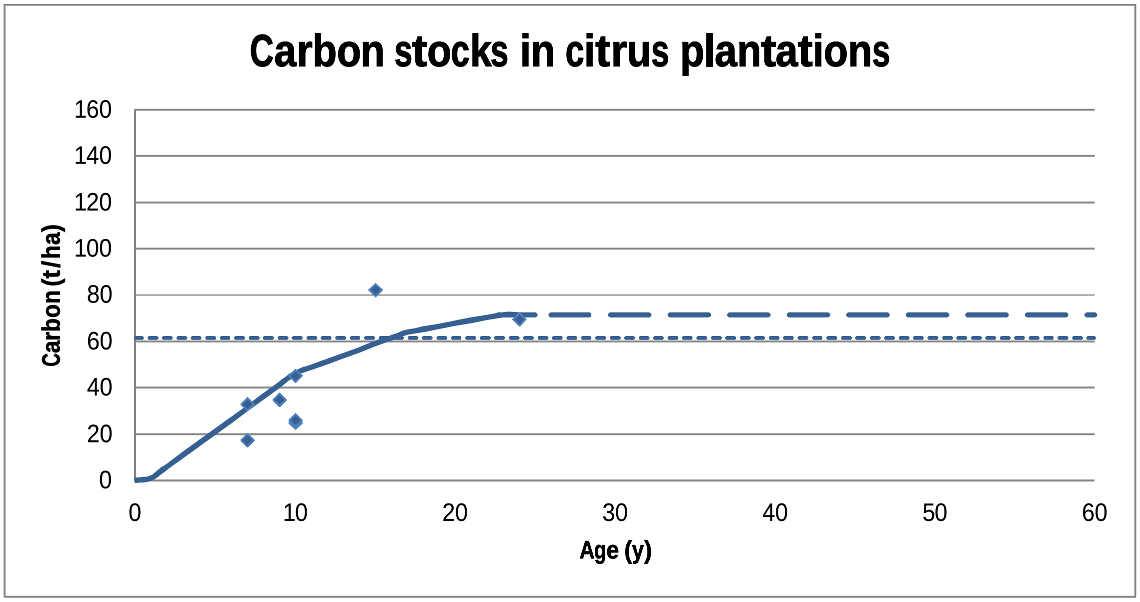

Figure 9 Carbon stocks in citrus plantations

Konsager et al. (2012) found aboveground carbon stocks of 76 tons in a 25-year-old citrus plantation at the ARC in Kade, leading to an annual sequestration rate of 3.1 tC/ha. Including belowground carbon, 95 tons are stored in such a system. Thus the carbon potential for citrus is even higher than assumed from the data obtained in the AOB district. The differences could be explained by the fact that the respective study was done on a research station with optimal management practices. The smallholder farmers in the respective district often neglect their farms due to the lacking market. As a consequence, weed pressure is very high and could have an influence on the growth of the citrus trees. Be that as it may there is not enough data available to support this statement.

An additional advantage of citrus is that the wood can still be used after the trees have been felled. That means that the carbon sequestered during a lifespan of 60 years is stored for even a longer time after that. Whether the wood is actually used by the citrus farmers of the AOB district has not been investigated.

Economic performance

Two tons of citrus are sold for 400 - 600 GHC (180 - 270 USD) on the market (Ofosu-Budu 2013b, personal communication). Average yields vary between 5 - 20 t (ibid). Because of the neglected state of the farms in the AOB district a mean yield of 10 t is assumed. Thus a potential income of 1125 USD/ha can be generated each year.

However, these calculations are based on the assumption that there is a reliable buyer for the fruit. The major problem faced by citrus farmers is the lack of a stable market. According to Ainoo (2011), most citrus and lime farmers in the Central Region have abandoned their farms due to a lack of interested buyers and no managing unit for the sector. In earlier years there used to be a processing facility close to the AOB district, but according to some of the farmers, the timing of the transport caused problems. A big part of the produce got spoilt because of this. At present, farmers try selling to middlemen who bring the fresh fruit to sellers on local markets. In these cases, there are no clear arrangements and the farm gate price is very low.

Potential improvements

Citrus production in West Africa has not received much attention in research. Therefore, not many possibilities to improve cultivation practices have been thoroughly studied. This is particularly the case for small-scale production in Ghana and any other country in West Africa. Nonetheless, it is clear that physical access to markets should be pursued even before conducting research on cultivation practices. Steps to improve market access include the following: Grouping citrus farmers in an association, organizing transport to the nearest processing facility in Assin Fosu or encouraging the formation of a new processing facility in the district. Additionally, the buyers' market needs to be analyzed in detail. The results can help identifying new potential consumers and their requirements. Afterwards the farming practices can be adjusted if necessary.

According to Manner et al. (2006) citrus oil can be used in cosmetics, soaps, cleaners, candles or as medicinals in aromatherapy. Therefore another possibility that needs to be further explored is whether the orange peels could be sold to Portal Ltd for distillation in order to produce essential oil.

Potential for REDD+

The major advantage of citrus is that its economic lifespan exceeds all other crops. As the improvement of livelihoods is an important aspect of REDD+, the future potential of this land use system highly depends on the development of the citrus market.

4.3.4 Rubber plantation

Biophysical characteristics

Rubber is the newest of the existing land use systems. It has been introduced to the AOB district only recently. Thus only young plantations with a maximum age of seven years were considered in the research. Rubber production is set up in an outgrower scheme (Agyarko 2013, personal communication). Race and Desmond (2001) define an outgrower scheme as "a contractual partnership between growers or landholders and a company for the production of commercial forest products". Related to this arrangement, rubber plantations are generally bigger in size than the other agricultural plantations in the AOB district. Compared to the other farms, rubber plantations were also better managed. The conditions (prevalence of weeds, soil structure, tree management) were good on all sample plots except one. This could also be linked with the fact that rubber farmers meet an extension agent several times a year and are relatively satisfied by the services.

Rubber is planted gradually. Every other year more land is cleared to expand the plantation until it has reached its intended extent. During the years of establishment, all of the traditional food crops with the exception of cassava are cultivated (table 6). Harvesting cassava could uproot the trees, whose side roots are 7 - 10 m long (Rehm and Espic 1991). Plantain is planted in rows between the rubber and is used for as long as it produces fruit. Sometimes it can even be found in mature plantations if the lighting conditions allow it.

Table 6 Cropping pattern in a rubber plantation

Year	1	2	3	4	5	6	7	8	9	10-40	40-60
Maize	X										
Cocoyam	O	X	X	X							
Plantain	O	X	X	X	(X)	(X)	(X)	(X)			
Rubber	O	O	O	O	O	X	X	X	X	X	(X)

Legend: O: crop is present X: harvest

Seeing that rubber plantations follow a strict planting pattern, usually all of the land is cleared at the beginning and no other trees are left standing. Only on one of the farms a large timber tree was conserved between the rows of rubber trees. It is however an exception rather than common practice.

If managed well, the economic lifespan of a plantation can be 30-35 years (Rehm and Espic 1991). In the district it is yet to be experienced whether such a lifespan can be achieved under the prevalent conditions. For now it is assumed that rubber will stand for 40 years before it is replanted. After that, the wood can still be used locally as construction material.

Carbon stocks

Figure 10 illustrates how rubber trees already sequester a high amount of carbon during early years of establishment. The annual sequestration rate during the first 15 years is approximately 6 t/ha. Experience with other trees show that the growth rate eventually slows down and then remains at a low level after around 20 years. Hence for rubber it is also assumed that maximum carbon storage is reached after 20 years. Average stocks are 92.6 tC/ha. On the sample farms only 6% of the carbon is stored in trees other than rubber.

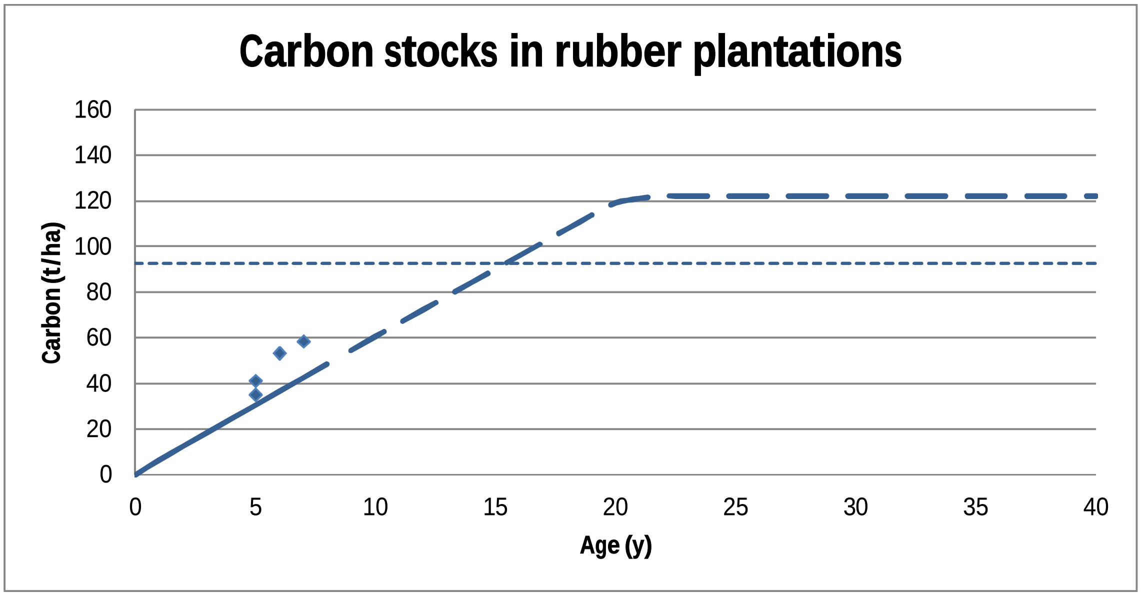

Figure 10 Carbon stocks in rubber plantations

Saengruksawong et al. (2012) found comparable results in early years and a maximum of 122 t/ha in a 20-year-old plantation. In younger plantations they found 12, 31, 58 and 80 t/ha after 1, 5 10 and 15 years respectively. Konsager et al. (2012) found a comparable above-ground carbon stock of 61.5 t/ha in a 12-year-old plantation. Another study done by Wauters et al. (2008) in Western Ghana came to a similar conclusion with an amount of 76.3 tC/ha aboveground for 14-year-old rubber plantations.

Given the fact that rubberwood can still be used after felling, carbon stocks potentially remain for a longer time after the economic lifespan of a plantation has ended.

Economic performance

The labour costs which are not included in this calculation are higher than for other systems, especially for the harvest. A tapper needs to be hired permanently so that the trees are harvested regularly during nine months. One of the disadvantages of rubber production is that from March to May no income is generated (Owusu 2013, personal communication). The outgrowers are provided with seedlings and other inputs and sell their produce to the processing company for a fixed price. On average a yearly income of 2228 USD is achieved.

Potential improvements

In the setting of the AOB district the planting distance is predetermined. To improve the systems the planting pattern would have to be adjusted. One approach is to plant the tree crops in wide rows 20 m apart and keep a distance of 1 - 2 m within the rows in order to reduce labour costs (Rehm and Espic 1991). On the other hand there is also the possibility to plant food crops or even trees in between the rows.

Potential for REDD+

Beyond doubt rubber production should be included in a REDD+ scheme. Not only is *Hevea brasiliensis* a fast-growing tree which sequesters a high amount of carbon in a short period of time, but it is also a lucrative crop for smallholders. Risk is rather low because of the reliable market. It is thus important that farmers are aware of the benefits of this new crop.

4.3.5 Portal Plantation and essential oil crops

Project description

Green Dreams Limited, a subsidiary of Portal Limited, is the lead organization for a managed forest estate concept in Bedum in the AOB district (Baiden et al. 2012). The philosophy is the conservation of forest resources as well as income improvement of the forest communities (ibid). Land was acquired in the year 2000. While a part of the original forest land is conserved, the degraded farmland is used for reforestation and agroforestry production systems where high-value essential oil crops play the main part. Essential oils are "liquid products of steam or water distillation of plant parts such as leaves, stems, bar, seeds, fruits, roots and plant exudates" (UNIDO and FAO 2005). The company plans to expand their production by hiring farmers in the district as outgrowers for essential oil crops. Once the project is functioning and income is generated, more activities are planned: Learning centre, eco lodge, monkey sanctuary, butterfly farm, beekeeping and honey production, just to name a few.

Biophysical characteristics

Figure 11 Map of the Portal Plantation, own illustration

The land is divided into six zones for different crops (figure 11): 30 ha conservation area with natural forest, 20 ha timber plantation, 15 ha ylang ylang (*Cananga odorata*), 8 ha flower farm, and 5 ha each for nutmeg (*Myristica fragrans*) and black pepper (*Piper nigrum*) (Baiden 2013b, personal communication).

System 1: In the conservation area, the existing forest had been degraded at the beginning of the project in 2000. It was restocked through strip planting of indigenous tree species in order to build up carbon stocks and support biodiversity.

System 2: The timber plantation has been established at the beginning of the project and is now about 10 years old. *Cedrela odorata* is a fast-growing timber species and is commonly produced as a monoculture during 20-25 years.

System 3: Ylang ylang (*Cananga odorata*) is a small tree with strongly scented flowers. They are often used in the cosmetics industry, mainly for perfumes. In order to have an optimal output the trees are cut at a height of about 2 m. This leads to coppicing and an elevated formation of flowers. On the Portal Plantation, lemongrass, citronella and patchouli are grown in an agroforestry production system under the ylang ylang. Some timber trees are currently present on the land. However, these are planned to be felled because the crop yields better under full sun (Amoako 2013a, personal communication).

System 4: Black pepper is a climber and is grown in association with *Gliricidia sepium* at the Portal Plantation, whereas the pollards serve as firewood supply and potentially forage for livestock. When coppices are ready for harvest the trees are cut at about 2.2 m height (Baiden et al. 2012) and the firewood is sold. In the near future the intention is to further process it into charcoal, which has a better market price. Together with black pepper it is also planned to intercrop lemongrass, citronella and patchouli. Even though it grows well under light shade (Nelson and Cannon-Eger 2011), too much shade from timber trees should be avoided.

System 5: Nutmeg trees are long-lived spice trees which can be productive for up to 60 years (FAO 1995). At the Portal Plantation they were planted in 2010 (Amoako 2013a, personal communication). Because of maintenance problems the survival rate of the seedlings was small. Strip planting is now used as a method to put together the nutmeg plantation. Cinnamon is planned to form part of this system. Early-yielding crops (lemongrass, citronella, patchouli) will also be intercropped.

System 6: The flower farm was established in 2010. Orchids and *Heliconia spp* are cultivated for the purpose of cut flower production. Heliconia requires a shade level of 30-50% (Orchids Asia 2006), even though at the moment there are no large trees present in this system.

Other essential oil crops, such as geranium, vanilla, cardamom and coriander could be introduced in the agroforestry systems or even in the shade of the conservation area (Baiden 2013a, personal communication). Table 7 gives an overview of the several existing systems of Portal Ltd and their cropping and harvesting pattern.

Table 7 Cropping systems at the Portal Plantation

Year	1	2	3	4	5	6	7	8	9	10-25	25+
System 1											
Forest trees	O	O	O	O	O	O	O	O	O	O	O
Planted trees	O	O	O	O	O	O	O	O	O	O	O
System 2											
Cedrela	O	O	O	O	O	O	O	O	O	O	X
Forest trees	O	O	O	O	O	O	O	O	O	X	
System 3											
Lemongrass	X										
Citronella	X	X	X								
Patchouli	X	X	X								
Ylang ylang	O	O	X	X	X	X	X	X	X	X	
System 4											
Lemongrass	X										
Citronella	X	X	X								
Patchouli	X	X	X								
Black pepper	O	O	O	X	X	X	X	X	X	X	
Gliricidia	O	O	X	X	X	X	X	X	X	X	
System 5											
Lemongrass	X										
Citronella	X	X	X								
Patchouli	X	X	X								
Cinnamon	O	O	O	X	X	X	X	X	X	X	X
Forest trees	O	O	O	X	(X)	(X)					
Nutmeg	O	O	O	O	O	O	X	X	X	X	X
System 6											
Flowers	X	X	X	X	X	X	X	X	X	X	X

Legend: O: crop is present X: harvest

Advantages and disadvantages of selected essential oil crops

Some of the essential oil crops have already successfully been cultivated on the Portal Plantation as well as on a few farms in Bedum. Advantages and disadvantages for smallholder cultivation, according to different sources (Nair 1980; Thankamani et al. 1994; Nelson and

Cannon-Eger 2011; Chandy no date; Bapat et al. 2012) and own observations, are illustrated in table 8.

Table 8 Advantages and disadvantages of selected essential oil crops (Nair 1980; Thankamani et al. 1994; Nelson and Cannon-Eger 2011; Chandy no date; Bapat et al. 2012)

Crop	Advantages	Disadvantages
Black Pepper	- already known by the farmers - tolerates shade - cultivation with live supports (e.g. coffee, cocoa, forest trees) - can be sold as spice	- no quick economic returns - high labour costs
Cardamom	- partial shade preferred	- first harvest after 3 years
Cinnamon	- adaptable to shade - suitable for marginal areas - suitable for low-input systems	- no early income
Citronella	- early economic returns	- low market price
Lemongrass	- simple cultivation techniques - disease and pest resistant - soil conservation in marginal areas and on degraded lands - high market demand	- low-value oil
Nutmeg	- high oil yield	- long-term investment
Patchouli	- early economic returns	
Ylang Ylang	- already known by the farmers - maximum flower production between november and march	- rapid harvest & transport necessary

Carbon stocks

The conservation forest, which has been standing for numerous years, is at a stable level of 126 tC/ha. Over a lifespan of 25 years *Cedrela odorata* supposedly reaches a maximum of over 150 tC/ha with a mean of 114.7 tC/ha. Average carbon storage of timber plantations can be increased if the trees were sold at a later stage. The agroforestry systems with the essential oil crops on the other hand only sequester carbon during the first years. After coppicing at a height of 2 m tree diameter stops increasing and growth is limited to coppices, which are regularly used as fuelwood. Therefore the carbon stocks of these systems remain stable after the initial build-up. Out of all essential oil crops, the black pepper agroforestry system sequesters by far the highest amount of carbon (figure 12). With an average storage capacity of 60.2 tC/ha its potential as carbon sink is more or less three times as high as that of ylang ylang (18.9 tC/ha) and nutmeg (23.9 tC/ha).

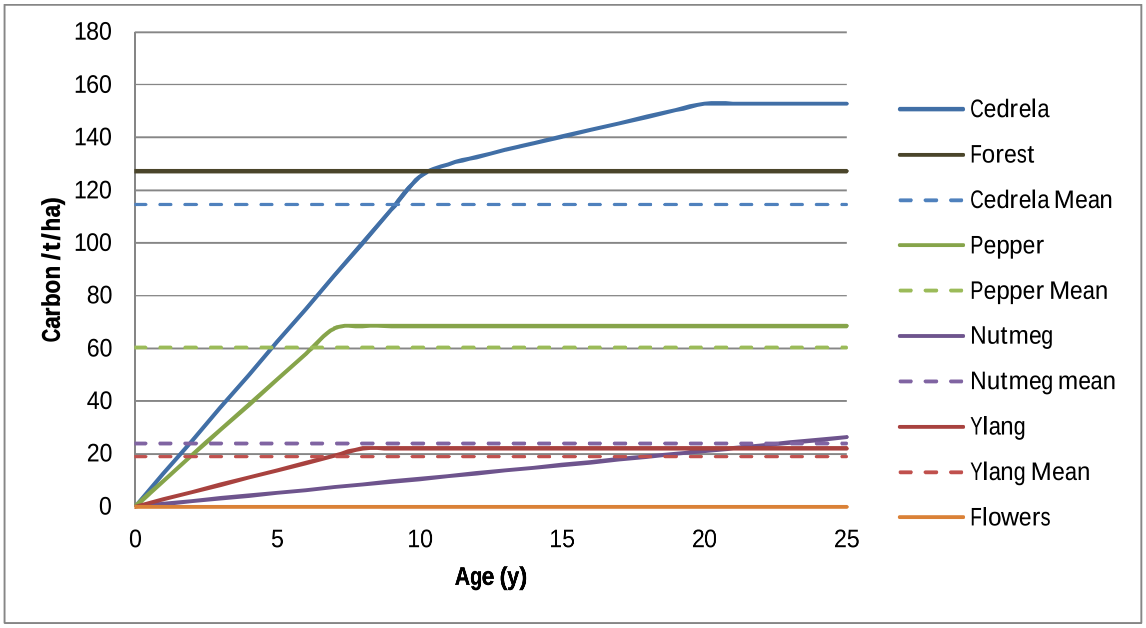

Figure 12 Carbon stocks at the Portal Plantation (approximate curve)

Considering the average carbon stocks in all systems as well as their prevalence on the land of Portal Ltd, a total amount of 81.3 tC/ha are stored (table 9).

Table 9 Average carbon stocks at the Portal Plantation

	Carbon (t/ha)	Area (ha)	Total (tC)
Forest	126	30.4	3824.1
Cedrela	114.6	20.2	2318.4
Ylang ylang	18.9	15.4	290.7
Black pepper	60.2	5.3	316.7
Nutmeg	23.9	5.3	125.7
Flowers	0	8.1	0
Average	**81.3**	84.6	6875.5

At the flower farm there are no shade trees present. *Heliconia spp* do however require a shade level of 60%, which is why it is intended to plant fruit trees such as papaya (*Carica papaya*) in a pattern of 5 m planting distance (Forster 2013a, personal communication). Presuming the average biomass of all papaya trees found in the sample farms and a number of 400 trees/ha an additional 9.1 tC/ha would be stored on the flower area. With that, total carbon stored at the Portal Plantation could reach 82.2 t/ha.

Economic performance

An assessment of the potential income from essential oils production is difficult for several reasons. First, nowadays most of the suggested crops are cultivated in Asian countries where growing conditions are different. Second, the reliability of the market is unclear. Third, there is not much information available concerning the costs of the production (especially labour costs) which farmers would have to put in. Also, the investment costs are supposedly very high, considering that the outgrowers would adopt a completely new production system. Investment costs include land purchase, land preparation, training and inputs.

For most crops only a small amount of oil can be extracted from the harvested and dried produce. The oil yield lies between <1 - 15%. This means that a lot of organic waste will be produced during the distillation process. Portal Ltd intends to use those leftovers as mulch for flowers and other crops.

Table 10 Income at the Portal Plantation

	$\text{Income}_{\text{Portal Ltd}}$ (USD/ha/y)	Area (ha)	Total (USD/ha/y)
Forest	0	30.4	0
Cedrela	2380.5	20.2	48'167.0
Ylang ylang	18'924.8	15.4	291'025.0
Black pepper	22'910.9	5.3	120'534.2
Nutmeg	25'259.1	5.3	132'888.0
Flowers	8'139.6	8.1	65'881.9
Average	**7'785.6**	84.6	658'496.1

Prices for a kilogram of essential oil differ highly among the crops. The highest amount is paid for black pepper and ylang ylang. All in all an annual income of 7'785.6 USD/ha is generated at the Portal Plantation (table 10)

It is assumed that farmers can deliver their harvest from the essential oil crops as well as from flowers to Portal Ltd for half the price the company receives when they sell the processed products. For outgrowers, both nutmeg and black pepper bring a very high annual income with 12'629.5 USD/ha and 11'455.4 USD/ha respectively. Ylang ylang generates 9'462.4 USD/ha/y. Comparable results can be obtained with flowers (8'139.6 USD/ha/y). For cedrela 59'512.5 USD/ha are paid, which are 2380.5 USD/ha for each year. Even though income is lower than for essential oils labour costs are in general rather low. For smallholders timber plantations have the disadvantage that long-term investments are necessary. Another influencing aspect is land tenure. The conservation area does not generate any income at the moment. Nonetheless in the future possible income could either come from touristic activities (eco lodge) or from essential oil crops which are cultivated under the forest canopy.

Potential improvements

Portal Ltd has gained a lot of experience in cultivating essential oil crops during the last 10 years. But in general not much knowledge is available, especially in the West African context. Adjustments to the cultivation practices and crop combinations are still being made. Some experience with producing and marketing essential oil crops has been made in Madagascar, Mozambique and South Africa.

In addition to the existing crops it is planned to cultivate further essential oil plants (e.g. vanilla, cardamom, coriander) underneath the conservation forest. This is another good opportunity for farmers to produce high-value crops while also safeguarding forest land.

Farmers' perception

Out of the 32 interviewed farmers in the AOB district, 84% are interested in the essential oil crops. Their main interest lies in black pepper, because they already know the plant. They would be willing to start out on a small plot of land (around half a hectare) with this crop. Apart from black pepper mainly short rotation crops such as lemongrass, citronella and patchouli are of interest for the people. Early economic returns are very important especially in the beginning of the project. The company therefore has to accept that farmers will not invest in long-lived crops, at least not in the first few years. Then if they see there is a good market for essential oils they would start with other proposed crops on additional land. 47% of the farmers already have enough land at their disposal, while the rest of them would have to purchase new land. However, at present land appears to be easily accessible in most communities of the district. Only 19% believe they have enough labour capacity for a new crop, but all of them are willing to hire more labourers. This leads to the assumption that there is no shortage of labour in the district. Cost of labour in the AOB district is around 5 USD per worker per day (Owusu 2013, personal communication) even though these arrangements may differ depending on the work.

The biggest concern from the farmers' perspective is their lack of knowledge about the proposed crops. Although 6 farmers (19%) mentioned they have some experience with part of the essential oil crops, none of them have ever cultivated them on a commercial basis. This is why training of farmers and hired workers should be a key activity.

A further worry is the dependence on one buyer. There are major trust issues mainly between farmers of the Bedum community and Portal Ltd. Ten years ago those farmers had already been involved in the cultivation of essential oils and were disappointed when they could not sell their produce do to the absence of a distillery at the Portal Plantation. These farmers are now sceptical towards the company and not willing to cultivate those crops unless they have a secure market access.

Potential for REDD+

The project fits well in a REDD+ mechanism. On the one hand carbon is conserved in forest trees as well as fast-growing timber species. Furthermore, cultivating essential oil crops in agroforestry systems serve as an additional carbon sink. On the other hand there is a very high income potential for the farmers as well as employment opportunities for the other members of the community. For the project as well as the individuals it is crucial that the land use is profitable and sustainable even without potential carbon credits. Payments for ecosystem services would just serve as an additional source of income.

Further constraints

The project faces different challenges at the moment. Lack of finance for investments is the number one hindering factor. One concern is the poor condition of the roads. For essential oil crops it is crucial to have a quick and efficient mode of transport between the farmers' fields and the processing facility. If transport takes too long the oil inside the plant parts can either evaporate or decline in quality (DAFF 2011). Ylang ylang for example should be distilled as soon as possible to avoid fermentation (UNIDO and FAO 2005). The same goes for the other spice crops. In order to reduce post-harvest losses, a functioning transportation system needs to be in place. In addition, other necessary infrastructure such as storage and drying facilities should be set up before starting the production on a larger scale. Due to the limited knowledge of the farmers and workers, good training is critical. Not only the farmers but also the labourers at the distillery need to be instructed on how to handle essential oil crops. This work requires a high level of technical skills, which should not be underestimated. The Department for Agriculture, Forestry and Fisheries (DAFF 2011) mentions the necessity for highly focused field maintenance for high-quality produce as well as the requirement of technical support such as inputs and good-quality planting material as the major production constraints. All in all, the production of essential oils will generate a lot of employment opportunities. As a result labour costs are very high and should be considered accordingly.

A very important matter in the essential oils industry are quality standards. According to MBB Consulting Services South Ltd (2006) consumers are not willing to buy products from a supplier whose sustainability is not recognized by means of certification. If possible, organic production should be pursued in order to satisfy global market demands. Time and effort for certification is typically fairly high, especially for small companies. An additional obstacle is the mistrust coming from European and North American market actors. Studies found that those consumers have the general perception that African producers are not reliable when it comes to delivering goods which are conform to international standards of quality (MBB Consulting Services South Ltd 2006). Accordingly, there is a strong request for traceability. It is thus a key goal to keep the essential oils value chain transparent from the farmers to the processing company.

5 Main discussion

5.1 Comparison of land use systems

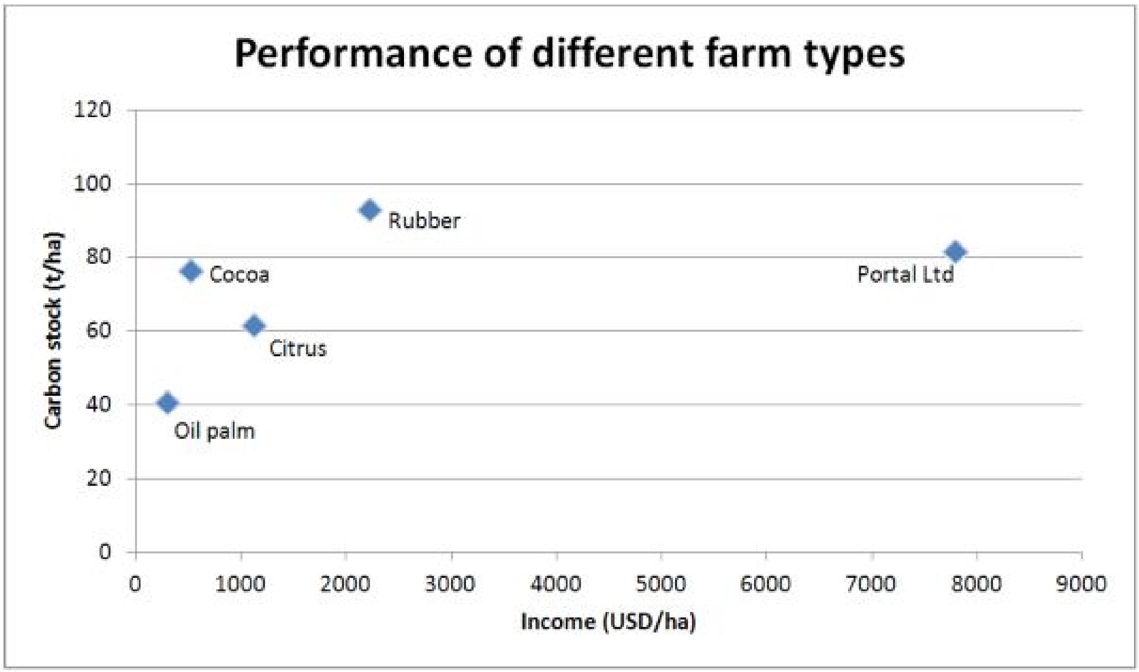

Figure 13 Comparison of the performance of different farm types

It is evident from figure 13 that the potential income of Portal Ltd is much higher than the one from farms with traditional crops. With an average income of 7785.6 USD/ha the economic benefits are several times higher than for all of the traditional crops.

On the other hand, production costs are also significantly higher than for the usual crops. A more accurate cost-benefit-analysis of the farming systems is necessary to compare the profitability of each land use. As for carbon benefits the differences are not immense. None-theless it is apparent that rubber has the highest carbon stocks with 92.6 t/ha, followed by Portal Ltd (81.3 t/ha) and cocoa (76.3 t/ha). Citrus also has acceptable carbon storage with an average of 61.4 t/ha. The smallest amount of carbon is stored in oil palm plantations (40.5 t/ha). In general it can be said that both Portal Ltd and rubber plantations have the best po-tential for REDD+.

Figure 14 indicates that in the AOB district there are two main types of land use systems: carbon intensive systems with low- or middle-value crops and low-carbon systems with high-value crops for export. For small-scale farmers, the decision which crops they will cultivate depends on the economic benefits rather than carbon storage.

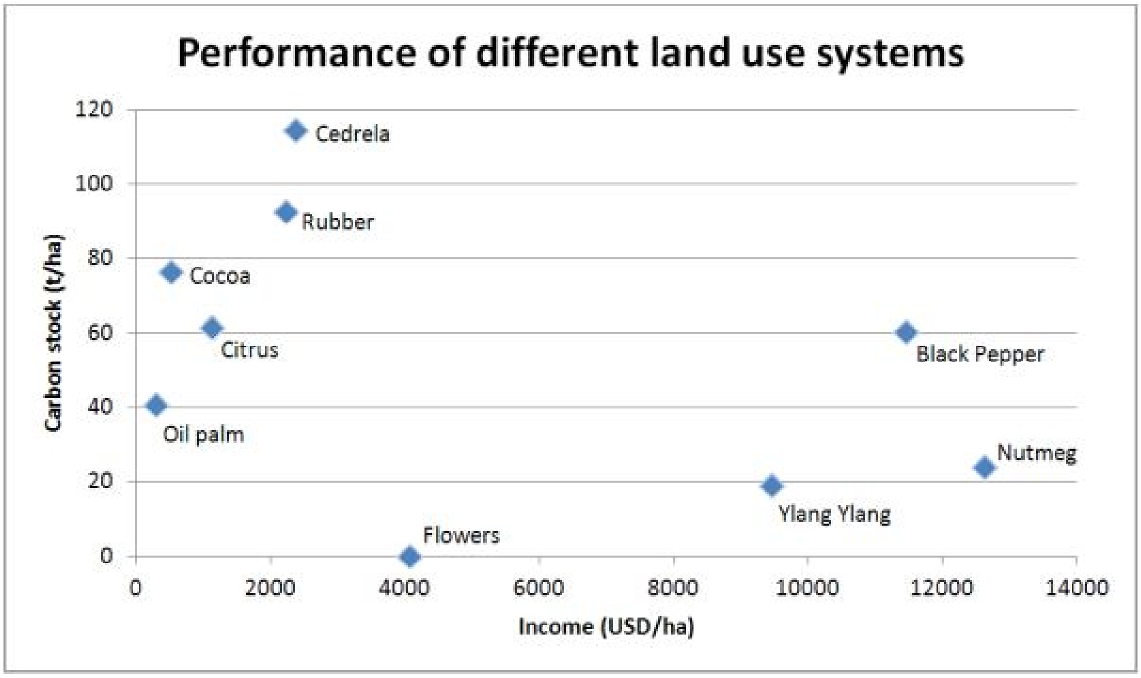

Figure 14 Comparison of the performance of different land use systems

The individual systems of the Portal Plantation have widely different potentials. The carbon intensive structures (conservation area and cedrela plantation) are less lucrative. The essential oil crops on the other hand have a high market price but only sequester a limited amount of carbon. It seems that from all the essential oil cropping systems, the most appropriate one in terms of REDD+ is agroforestry with black pepper.

5.2 Proposed land use systems for smallholders

In table 11 scores from 1 - 10 are given according to the systems' rank concerning carbon storage and income generation. This outline is meant as a guideline for farmers to help choose the land use systems which are suitable from their prospective and profitable in a REDD+ mechanism. Cedrela reaches by far the highest score. From the essential oil crops black pepper is the most promising alternative, followed by nutmeg. Out of the traditional tree crops rubber is the one with the highest carbon storage as well as the biggest income. Citrus and cocoa are similar while oil palm is clearly the crop with the least potential for REDD+.

Table 11 Ranking of the different land use systems

	Crop	Advantages	Disadvantages	Score C	Score $	Score tot	Rank
++	Cedrela	- low labour costs - excellent carbon sink	- no income for 25 years	9	6	15	1
+	Black pepper	- local market for spices - firewood from live stakes		5	9	14	2
	Rubber	- growing market - good carbon sink	- no cassava intercropping - dependence on buyer	8	5	13	3
	Nutmeg	- high price for oil - long economic lifespan	- late maturity	3	10	13	3
+/-	Forest	- diverse forest products	- no income	10	1	11	4
	Citrus	- long economic lifespan	- insecure market	6	4	10	5
	Cocoa	- good market conditions - a lot of research done	- low price	7	3	10	5
	Ylang ylang	- yields all year round	- critical harvest - high labour requirement	2	7	9	6
	Flowers	- very high market price	- poor carbon sink	1	7	8	7
-	Oil palm	- grows on marginal soils - home consumption	- low market price - short economic lifespan	4	2	6	8

Legend: ++ very high potential + high potential +/- moderate potential - low potential

Seeing that minimizing risks is a key tactic for smallholders, a diversified farming strategy should be promoted. Judging from table 11, the best investment is having at least one timber plantation of around 1 ha, be it *Cedrela odorata* or any other fast-growing species. In addition to that it is suggested to plant approximately 1 ha with essential oil crops, guaranteeing a high income even in early years. The most appropriate of these is black pepper in combination with annual crops (lemongrass, citronella, patchouli). Apart from the good carbon and economic performance black pepper is also known by the farmers plus the risk of market failure is smaller than for the other crops because it can be sold unprocessed as a spice. When the essential oils value chain is well established farmers can choose to invest in another crop like nutmeg or ylang ylang. Further cultivation of traditional crops is also recommended (1 - 2 ha). If a farmer wants to keep producing the existing crops rubber has the highest potential. On the other hand, cocoa production with improved cultivation practices could be very lucrative too. With better market opportunities, citrus farms have a good potential as well. Finally, it is strongly recommended that each farmer has a small plot of land which is solely used for the cultivation of food crops (0.5 - 1 ha depending on household size). In case the soil does not support intensive food cropping a form of shifting cultivation with fallows should be practiced on this land. The consequence is that a larger plot of at least 2 ha should be set aside for this cause.

In any case, this is not a fixed recommendation and can be adjusted for each farmer. Seeing that usually farm plots have a size of around 2 acres, it is most likely that each system will be practiced on less than 1 ha of total landholding. It should also be mentioned that due to the requirements for the sample plots the visited farms were probably slightly bigger than the average farm in the district. Smallholders are important stakeholders in the REDD+ mechanism and should not be disregarded. Nevertheless, a diversified farming strategy is also for them the main recommendation. It is assumed that a smallholder farmer is not willing to crop 1 ha of his land with a timber species. Therefore the most practical solution would be to manage a timber plantation on the community level.

Instead of having separate lands for each system, combinations of the individual crops are possible. One example is to plant cinnamon between rows of rubber (Pathiratna and Perera 2006) as an alternative to intercropping with nutmeg. Other likely combinations are citrus with flowers or annual essential oil crops, cocoa under forest shade or black pepper with timber trees as live stakes. It is evident that more studies need to be done on the potential of such combined land use systems.

On the district level, when comparing the carbon in the agricultural land use systems with the carbon stored in abandoned farms and secondary forest it seems that there is a slight gain when converting to agricultural land use. Sacred groves with stocks of 206.9 tC/ha (Amoako 2013b) are not subject to conversion (World Bank 2006). On the other hand carbon stocks increase if any other land in the district (secondary forest with 36.9 tC/ha, abandoned cocoa farm with 52.4 tC/ha, abandoned oil palm farm with 32.3 tC/ha or abandoned food crop farm with 4.3 tC/ha (Amoako 2013b) is converted. The increase is especially high if any of that land is converted to a cocoa, rubber or timber plantation. In perspective of an implementation of REDD+ in the entire district the suggestion is to improve the carbon stocks in secondary forests through enrichment planting of indigenous tree species and possibly produce shade-loving essential oil crops underneath the canopy. Eventually carbon stocks similar to the conservation area of Portal Ltd (126 t/ha) could be achieved. Abandoned farms on the other hand should be replanted with any of the above suggested crops.

Key to success seems to be a well-functioning extension service. Most of the interviewed farmers said that they do not have much information about adequate cultivation practices for their traditional crops. They added that for them to include new crops would require a lot of support from extension agents. For high-value crops it makes all the more sense to pass on as much knowledge as possible in order to avoid yield gaps as well as post-harvest losses. It is thus highly recommended that farmers are involved from the beginning of the process. In addition, the formation of farmers' groups should be encouraged to reach a better flow of information.

Other issues that have not been solved yet are land and tree tenure. Small-scale farmers will not make long-term investments when they are unsure about the ownership of the land. Also they will not conserve trees when not getting monetary benefits for them.

6 Conclusion

The major land use systems in the AOB district are perennial cash crops such as cocoa, oil palm, citrus and rubber in combination with food crops during 2 - 5 years. The most important food crops are maize, cassava, plantain and cocoyam. In all of these systems some naturally regenerated trees are present.

Out of all traditional land use systems, rubber stores the highest amount of carbon with a mean stock of 92.6 tC/ha and should therefore be promoted. The annual income of 2'228 USD/ha is underlining the importance of this crop. The second highest amount of carbon is stored in cocoa agroforests (76.3 tC/ha). Improvement of shade management is crucial to increase carbon sequestration as well as productivity and reach a higher income than the current 525 USD/ha/y. The potential for REDD+ is also good. The third highest amount of carbon is stored in citrus plantations (61.4 tC/ha). Potential yearly income is 1'125 USD/ha, but access to a processing facility is the key factor in order to be suitable for REDD+. The least carbon is stored in smallholder oil palm plantations (40.5 tC/ha), which are mainly used for household consumption and bring little additional income (300 USD/ha/y). Oil palm is thus of minor importance for REDD+. Portal Ltd with their six land use systems have comparably high carbon stocks (81.3 t/ha) and a much higher annual income (7'786 USD/ha). The results confirm that overall the proposed land use systems have a very high potential for REDD+.

It seems the pilot will have great benefits for the communities of the AOB district. As a conclusion, combinations of fast-growing trees with a high carbon sequestration rate and high-value essential oil crops are suitable for REDD+. For smallholder farmers a risk reduction strategy with a diversity of cash crops, timber trees and food crops is recommended. An ideal combination would be: 2 ha traditional crops (rubber, citrus or cocoa), 1 ha timber plantation, 1 ha essential oil crops (preferably black pepper) and 1 ha food crops. Where the original land is degraded secondary forest, enrichment planting with indigenous tree species should be carried out. In a later stage, shade loving essential oil crops such as vanilla can be cultivated underneath the forest canopy.

In contrast issues such as tree tenure, market access and the improvement of extension services need to be addressed in order for the pilot to be successful. Further research needs to be done on the composition of the agroforestry systems, interactions between different crops, suitable tree species as well as market opportunities of essential oils. Also the production costs of each land use system need to be included in a further analysis in order to give accurate information on the profitability. Another important aspect that has not been regarded so far are soil properties and the effect of the different crops on soil structure and availability of nutrients.

For future research in the AOB district it is important to include all stakeholders. In order for the pilot to be successful the different interests should be clear and addressed from the beginning. The communities as well as community leaders, extension agents and the company Portal Ltd should be involved.

7 Literature

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Annex

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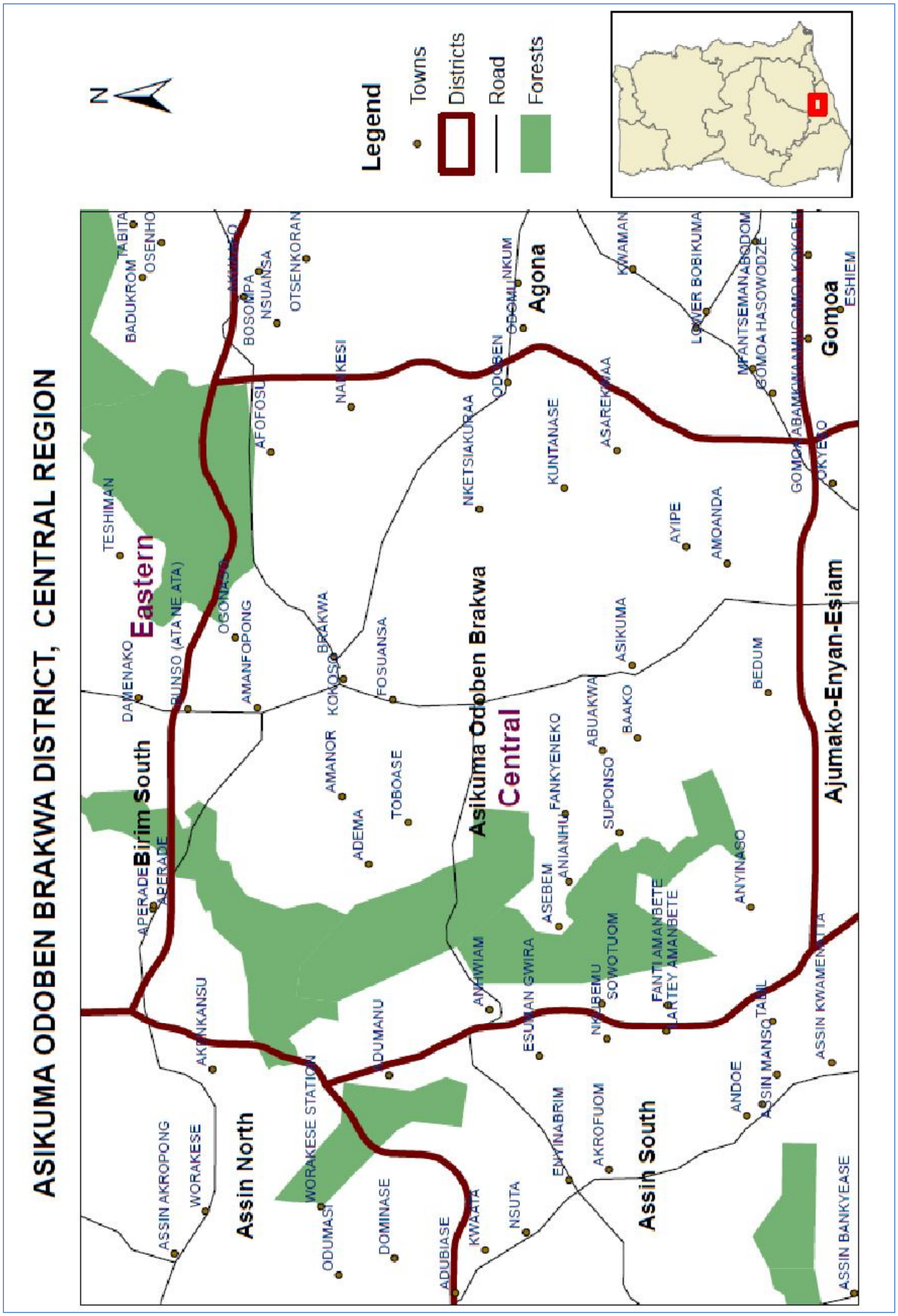
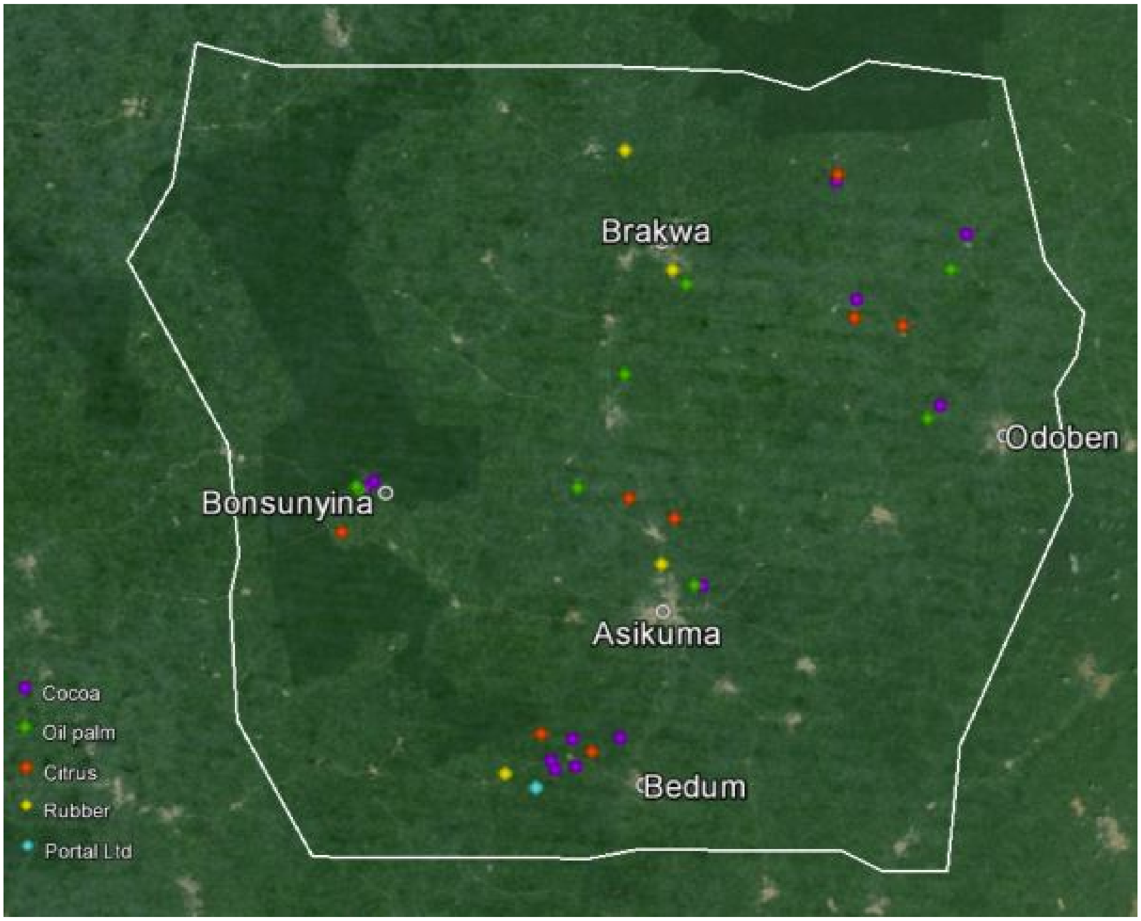
Annex 1: Map Asikuma-Odoben-Brakwa district



Annex 2: Map sample plots



Annex 3: Pictures Cocoa

Young cocoa farm intercropped with plantain, cassava and cocoyam (Photo: Mélanie Feurer)

Young cocoa farm (Photo: Mélanie Feurer)

Mature cocoa farm (Photo: Mélanie Feurer)

Mature cocoa farm with large tree (Photo: Mélanie Feurer)

Annex 4: Pictures oil palm

Young weed infested oil palm farm (Photo: Mélanie Feurer)

Young mature oil palm farm (Photo: Mélanie Feurer)

Mature oil palm farm (Photo: Mélanie Feurer)

Well managed mature oil palm farm (Photo: Mélanie Feurer)

Annex 5: Pictures citrus

Mature citrus farm (Photo: Mélanie Feurer)

Mature weed infested citrus farm (Photo: Mélanie Feurer)

Well managed mature citrus farm (Photo: Mélanie Feurer)

Mature citrus with plantain (Photo: Mélanie Feurer)

Annex 6: Pictures rubber

Young rubber plantation with plantain (Photo: Mélanie Feurer)

Young mature rubber plantation (Photo: Mélanie Feurer)

Weed infested young rubber plantation (Photo: Mélanie Feurer)

Young mature rubber plantation (Photo: Mélanie Feurer)

Annex 7: Pictures Portal Plantation

Cedrela odorata plantation (Photo: Mélanie Feurer)

Ylang ylang plantation (Photo: Christoph Studer)

Black pepper on *Gliricidia sepium* (Photo: Christoph Studer)

Ylang ylang flowers (Photo: Christoph Studer)

Flower farm with *Heliconia spp* (Photo: Mélanie Feurer)

Nursery (Photo: Saskia Sportel)

Annex 8: Field protocol

No: ______________

Farmer: ____ **Date**: ___________________

Sex: □ Male □ Female **Age**: □ 20-40 □ 41-60 □ >60

Education level: □ illiterate □ primary □ junior high school □ senior high school □ tertiary

Village: ______________________ **Area:** ______________ **Coordinates**: ____________

Farming system: □ 1 Cocoa □ 2 Oil palm □ 3 Citrus □ 4 Rubber **Distance:** _______________

Date of establishment: ___________________________________ **Age**: ___________________

Other crops: ____

Description of Farming System

____

____

Description of physical environment (topography, soil, neighbouring land, condition of plot)

____

____

1. Land tenure: □ Owner □ Lease for __ years □ ________________________________

2. Crops

	Species	Years	Harvest	Yield	Use	Area	Price	Costs/Labour	Benefit share
1					Cons.: ____ Sale: _____				
2					Cons.: ____ Sale: _____				
3					Cons.: ____ Sale: _____				
4					Cons.: ____ Sale: _____				
5					Cons.: ____ Sale: _____				
6					Cons.: ____ Sale: _____				

3. Do you have to buy food? How much?

□ Maize: ______ □ Rice: _______ □ Cassava: ______ □ Yam: ______ □ Cocoyam: _______

□ Beans: _______ □ Vegetables: _______ □ Fruit: ________ □ Meat: _______ □ Fish: ____

4. Where do you get your fuelwood from? How much?

□ Own farm: ________ □ Secondary Forest: ________ □ Fallow: ________ □ Market: _______

4. a) How satisfied are you with the extension service: □ Very good □ Good □ Okay □ Bad

b) Association: □ Yes □ No

c) How often do you see an extension agent? □ 1x/w □ 2x/m □ 1x/m □ >1x/y □ 1x/y □ never

d) Do you get extension service on trees? □ Yes □ No

e) Do you need extension service on the management of trees? □ Yes □ No

5. What interactions between trees and crops do you observe?

____

6. Are you interested in planting more trees on the existing farm?

Species	**No**	**Uses**	**Constraints** (competition for water/nutrients/shade, lack of seedlings, lack of land, tree tenure, labour, ...)

7. a) Do you have to make an agreement with the land owner to plant trees? □ Yes □ No

b) Do you have to acquire more land if you want to plant more trees? □ Yes □ No

c). Do you have the possibility to acquire more land? □ Yes □ No

□ If: ____________________

8. a) Do you know the essential oils project? ◻ Yes ◻ No

a) Are you interested in producing essential oil crops? ◻ Yes ◻ No

b) Why (not)?____

c) Which crops are you interested in? ____

d) How many acres? ____

e) Capacity for the introduction of essential oil crops

	Present state	Accessibility	Remarks
Land	◻ Yes ◻ No	◻ Yes ◻ No	
Labour	◻ Yes ◻ No	◻ Yes ◻ No	
____________________	◻ Yes ◻ No	◻ Yes ◻ No	
Experience	◻ Yes ◻ No ◻ Little		

Crop trees (DBH)

1		9		17		25		1		9		17		25	
2		10		18		26		2		10		18		26	
3		11		19		27		3		11		19		27	
4		12		20		28		4		12		20		28	
5		13		21		29		5		13		21		29	
6		14		22		30		6		14		22		30	
7		15		23		31		7		15		23		31	
8		16		24		32		8		16		24		32	

Trees

No	Species	DBH	Planted?	Use	Benefits	Remarks
1			□ Yes □ No	a) b) c)	a) b) c)	
2			□ Yes □ No	a) b) c)	a) b) c)	
3			□ Yes □ No	a) b) c)	a) b) c)	
4			□ Yes □ No	a) b) c)	a) b) c)	
5			□ Yes □ No	a) b) c)	a) b) c)	
6			□ Yes □ No	a) b) c)	a) b) c)	
7			□ Yes □ No	a) b) c)	a) b) c)	
8			□ Yes □ No	a) b) c)	a) b) c)	
9			□ Yes □ No	a) b) c)	a) b) c)	
10			□ Yes □ No	a) b) c)	a) b) c)	

Annex 9: Prevalence of tree species

	Local name	Scientific name	Number of trees				Use					
			<10	10-29	30+	Total	T	R	F	C	M	O
1	Konkroma	*Morinda lucida*	39	38	3	80	X	X	X			
2	Pawpaw	*Carica papaya*	26	16	-	42				X	X	
3	Kakapenpen	*Rauvolfia vomitoria*	18	11	-	29		X	X		X	
4	Badua	*Phyllanthus muellerianus*	10	8	-	18		X	X		X	
5	Foto	*Glyphea brevis*	6	10	1	17			X			X
6	Sese	*Holarrhena floribunda*	12	5	-	17		X	X			
7	Nyankyerenee	*Ficus exasperata*	9	2	4	15			X			X
8	Ofram	*Terminalia superba*	2	7	-	9		X	X			X
9	Okoro	*Albizia glaberrima*	2	4	2	8		X	X			
10	Odum	*Milicia excelsa*	3	4	1	8	X	X	X			
11	Sweet Apple	*Annona squamosa*	7	1	-	8				X	X	
12	Funtum	*Funtumia elastica*	4	1	2	7		X	X		X	
13	Nwaduaba	*Ficus sur*	7	-	-	7			X			X
14	Cassia	*Cassia simea*	6	-	-	6			X			
15	Pear	*Persea americana*	2	3	-	5			X	X		
16	Nyamedua	*Alstonia boonei*	3	2	-	5		X	X		X	
17	Akye	*Blighia sapida*	5	-	-	5	X	X	X			
18	Citrus	*Citrus sinensis*	-	3	1	4			X	X		
19	Odom	*Erythrophleum suaveolens*	2	1	1	4			X			
20	Gyama	*Alchornea cordifolia*	4	-	-	4			X		X	
21	Kube	*Cocos nucifera*	-	2	1	3			X	X		
22	Onyina	*Ceiba pentandra*	1	1	1	3		X				
23	Pampena	*Albizia adianthifolia*	2	1	-	3		X	X			X
24	Atoa	*Spondias mombin*	1	2	-	3		X		X		
25	Pepediwuo	*Solanum erianthum*	3	-	-	3			X		X	
26	Mahogany	*Khaya ivorensis*	-	-	2	2	X					
27	Esa	*Celtis mildbraedii*	1	-	1	2	X	X				
28	Otwere	*Diospyros mobutensis*	1	-	1	2					X	
29	Obontoriwa	-	1	-	1	2		X	X		X	
30	Frafraho	*Dalbergiella welwitschii*	2	-	-	2			X		X	X

31	Milletia	*Millettia thonningii*	2	-	-	2			X		X	
32	Edwono	*Baphia nitida*	2	-	-	2			X		X	
33	Odwuma	*Musanga cecropioides*	-	-	1	1	X		X			
34	Tanaronini	*Paulinia pinnata*	-	-	1	1			X			
34	Awudifoampa	*Anthocleista nobilis*	-	-	1	1					X	X
35	Akata	*Bombax buonopozense*	-	-	1	1	X					
36	Hyedua	*Daniellia ogea*	-	-	1	1						X
37	Amango	*Mangifera indica*	-	1	-	1				X		
38	Edinam	*Entandophragma ango-lense*	-	1	-	1		X	X			
39	Tanuro	*Trichilia monadelpha*	-	1	-	1		X	X		X	
40	Mansonia	*Mansonia altissima*	-	1	-	1	X					
41	Akuakuo-Ninsuo	*Spathodea campanulata*	-	1	-	1		X	X	X		
42	Diboa	*Anthocarpu communis*	-	1	-	1				X		
43	Kumanini	*Lannea welwitschii*	-	1	-	1		X	X			
44	Kagya	*Griffonia simplicifolia*	1	-	-	1					X	X
45	Moringa	*Moringa oleifera*	1	-	-	1			X	X	X	
46	Wowoduaba	-	1	-	-	1			X			X
47	Cashew	*Anacardium occidentale*	1	-	-	1				X		
48	Awiemfosamina	*Albizia ferruginea*	1	-	-	1			X			X

Annex 10: Results questionnaires

Code	Crop	Village	Sex	Age	Education	$Land_{tot}$ (a)	Land tenure
1a-01	Cocoa	Bedum	F	41-60	junior high	6	lease 30 nu
1a-02	Cocoa	Bedum	M	20-40	primary	6	lease 30 nu
1a-03	Cocoa	Odoben	M	41-60	junior high	28	owner
1a-04	Cocoa	Odoben	M	41-60	junior high	8	owner
1b-01	Cocoa	Bedum	M	41-60	junior high	20	owner
1b-02	Cocoa	Brakwa	M	60+	senior high	23	owner
1b-03	Cocoa	Brakwa	F	60+	no schooling	75	owner
1b-04	Cocoa	Bonsunyina	M	41-60	no schooling	7	lease 50 nu
1c-01	Cocoa	Bedum	M	60+	junior high	7	owner
1c-02	Cocoa	Bedum	M	41-60	junior high	7	owner
1c-03	Cocoa	Bonsunyina	M	41-60	junior high	6	lease 35 nu
1c-04	Cocoa	Nankese	M	41-60	no schooling	8	lease 60 sa
2a-01	Oil palm	Asikuma	M	41-60	tertiary	4	owner
2a-02	Oil palm	Brakwa	M	60+	primary	15	owner
2a-03	Oil palm	Jambra	M	60+	junior high	45	lease 20 sa
2a-04	Oil palm	Bonsunyina	M	41-60	junior high	7	lease 20 nu
2a-05	Oil palm	Bonsunyina	M	41-60	junior high	7	lease 30 nu
2a-06	Oil palm	Benin	M	41-60	junior high	8	owner
2a-07	Oil palm	Odoben	M	60+	no schooling	17	owner
2a-08	Oil palm	Nankese	M	20-40	primary	21	lease 20 sa
3a-01	Citrus	Bedum	M	20-40	junior high	7	owner
3a-02	Citrus	Wasa Biampa	M	60+	senior high	19	lease 50 sa
3a-03	Citrus	Nkyeduam	M	20-40	junior high	6	owner
3a-04	Citrus	Asikuma	M	60+	tertiary	12	lease 40 nu
3a-05	Citrus	Benin	F	41-60	primary	17	owner
3a-06	Citrus	Kweku Ninson	M	41-60	junior high	11	lease 20 nu
3a-07	Citrus	Odoben	F	41-60	junior high	11	owner
3a-08	Citrus	Asikuma	M	41-60	senior high	51	lease 60 nu
4a-01	Rubber	Bedum	M	60+	tertiary	40	owner
4a-02	Rubber	Brakwa	F	20-40	no schooling	9	owner
4a-03	Rubber	Brakwa	F	41-60	junior high	12	owner
4a-04	Rubber	Asikuma	M	41-60	senior high	17	owner

Code	Buys Maize	Buys Rice	Buys Cassava	Buys Yam	Buys Taro	Buys Beans	Buys Veget	Buys Fruit	Dist (mi)	Age_{plot}	Size (a)	Cond
1a-01	Yes	Yes	No	Yes	No	Yeses	Yes	No	2	2	2	okay
1a-02	No	Yes	No	Yes	No	Yes	No	No	1	2	2	good
1a-03	No	Yes	No	Yes	No	Yes	No	No	6	2	8	good
1a-04	No	Yes	No	Yes	No	Yes	No	No	1	2	2.5	okay
1b-01	No	No	No	No	No	No	No	No	0.5	6	3	okay
1b-02	No	Yes	No	No	No	Yes	Yes	Yes	0.5	6	3	good
1b-03	No	Yes	No	No	No	Yes	No	Y	9	6	5	okay
1b-04	No	Yes	No	No	No	Yes	No	No	0.5	8	2	okay
1c-01	No	No	No	No	No	Yes	Yes	Yes	2	15	3	good
1c-02	No	No	No	No	No	Yes	No	No	2.5	20	4	okay
1c-03	No	Yes	No	Yes	No	Yes	No	Yes	1	15	2.5	good
1c-04	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0.5	20	4	good
2a-01	No	Yes	Yes	Yes	Yes	Yes	No	No	4	10	2	okay
2a-02	No	Yes	No	No	Yes	Yes	No	No	1	8	2	bad
2a-03	No	Yes	No	Yes	No	Yes	Yes	Yes	1	8	17	good
2a-04	Yes	Yes	No	Yes	Yes	Yes	No	Yes	2	15	2	bad
2a-05	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	1.5	15	2	good
2a-06	No	Yes	No	No	No	Yes	Yes	No	2	9	4	okay
2a-07	No	Yes	No	Yes	No	Yes	Yes	No	2.5	5	2	okay
2a-08	No	Yes	No	No	No	Yes	Yes	No	0.5	9	3	good
3a-01	No	No	No	Yes	No	No	No	No	3	7	4	okay
3a-02	No	No	No	No	No	Yes	No	No	1	24	4	bad
3a-03	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	0.1	9	1	good
3a-04	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	3	10	2.5	bad
3a-05	No	Yes	No	No	No	No	No	No	1	7	3	good
3a-06	No	Yes	No	Yes	No	Yes	No	No	0.5	10	2.5	bad
3a-07	No	Yes	No	Yes	No	Yes	Yes	Yes	3	15	2.5	okay
3a-08	No	Yes	No	Yes	No	Yes	No	No	5	10	11	bad
4a-01	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	4	6	4	good
4a-02	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	2	5	4	good
4a-03	No	Yes	Yes	Yes	No	Yes	Yes	Yes	2.5	5	5.5	bad
4a-04	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	2	7	12	okay

Code	$Trees_{tot}$	$Trees_{big}$	tC_{tot}	tC_{crop}	Assoc	Ext	$Perf_{ext}$	Ext_{trees}	Necessity
1a-01	34	3	3.8	0	No	1x/y	okay	Yes	Yes
1a-02	273	4	12.8	0	No	never	okay	No	Yes
1a-03	3	3	6.5	0	No	4x/y	okay	Yes	Yes
1a-04	293	0	7.3	0	No	never	bad	No	Yes
1b-01	184	4	22.4	13.3	Yes	1x/w	okay	Yes	Yes
1b-02	125	25	43.2	27	No	4x/y	good	Yes	No
1b-03	0	0	36.9	26.9	No	never	very good	No	Yes
1b-04	25	25	45.3	34.9	No	never	bad	No	Yes
1c-01	200	100	68.7	19	Yes	2x/m	very good	Yes	Yes
1c-02	175	100	93.2	26.9	Yes	2x/m	very good	No	Yes
1c-03	200	0	41.8	21.1	Yes	never	bad	No	Yes
1c-04	50	25	126.7	36.9	No	4x/y	good	Yes	Yes
2a-01	8	0	40.6	39.8	No	never	bad	No	No
2a-02	24	0	42.4	40.8	No	1x/y	okay	Yes	Yes
2a-03	20	4	56.5	50.2	No	1x/w	good	No	Yes
2a-04	12	0	46.5	46.2	No	1x/y	good	No	Yes
2a-05	0	0	53.8	53.8	No	never	bad	Yes	Yes
2a-06	56	0	38.9	38.4	No	never	bad	No	Yes
2a-07	0	0	46.7	46.7	No	never	bad	No	No
2a-08	16	0	66.6	64.5	No	1x/y	okay	Yes	Yes
3a-01	44	0	18.4	17.5	No	never	bad	No	Yes
3a-02	20	12	65.5	42.1	Yes	1x/y	good	No	No
3a-03	24	0	33.9	33.5	No	never	bad	No	Yes
3a-04	108	8	43.6	35	Yes	never	okay	No	Yes
3a-05	4	0	37.9	33	Yes	1x/y	very good	Yes	Yes
3a-06	4	0	25.8	24.8	No	never	bad	No	Yes
3a-07	36	0	77.5	77.1	No	1x/w	very good	Yes	Yes
3a-08	104	0	26.9	25.7	Yes	never	bad	Yes	Yes
4a-01	0	0	48.3	39.5	Yes	4x/y	very good	No	Yes
4a-02	0	0	76.9	37.3	Yes	1x/m	good	Yes	Yes
4a-03	75	0	66.7	33.2	Yes	4x/y	good	No	Yes
4a-04	0	0	54	54	Yes	4x/y	good	Yes	Yes

Code	Plant trees	Buy land	Project	Interest	$Capacity_{land}$	$Capacity_{labour}$	Experience
1a-01	Yes	No	Yes	Yes	Yes	No	No
1a-02	Yes	No	Yes	Yes	Yes	Yes	Yes
1a-03	Yes	No	No	Yes	Yes	No	No
1a-04	Yes	No	No	Yes	No	No	No
1b-01	No	Yes	Yes	Yes	Yes	No	No
1b-02	No	No	Yes	Yes	No	No	No
1b-03	No	Yes	No	No	No	No	No
1b-04	Yes	No	Yes	Yes	Yes	Yes	No
1c-01	No	Yes	No	Yes	Yes	Yes	No
1c-02	Yes	No	Yes	Yes	No	Yes	No
1c-03	Yes	No	No	Yes	Yes	No	No
1c-04	Yes	No	No	Yes	Yes	No	No
2a-01	Yes	Yes	No	Yes	No	No	No
2a-02	No	No	No	Yes	No	No	No
2a-03	No	No	No	No	No	No	No
2a-04	No	Yes	No	Yes	No	Yes	No
2a-05	No	Yes	No	Yes	Yes	No	No
2a-06	No	Yes	Yes	Yes	No	No	No
2a-07	No	Yes	No	Yes	Yes	No	Yes
2a-08	No	No	No	Yes	Yes	No	No
3a-01	No	Yes	Yes	Yes	No	No	No
3a-02	No	Yes	Yes	No	Yes	No	Yes
3a-03	Yes	No	No	Yes	No	No	No
3a-04	Yes	No	No	Yes	No	No	No
3a-05	No	No	No	Yes	Yes	No	Yes
3a-06	No	Yes	No	Yes	Yes	No	No
3a-07	No	No	No	No	Yes	No	No
3a-08	No	No	Yes	Yes	No	Yes	No
4a-01	Yes	No	Yes	Yes	No	No	Yes
4a-02	No	Yes	No	Yes	No	No	No
4a-03	No	No	No	No	No	No	No
4a-04	No	No	Yes	Yes	No	No	Yes

Annex 11: Results carbon calculations

Code	Crop	Rep	AGB/plot	AGB/ha	BGB/ha	Btot/ha	tC/ha
1a-01	Cocoa + Trees	1	2.05426	7.07632	1.76908	8.84541	4.42270
1a-02	Cocoa + Trees	1	5.37207	23.29605	5.82401	29.12006	14.56003
1a-03	Cocoa + Trees	1	4.45216	12.44663	3.11166	15.55829	7.77914
1a-04	Cocoa + Trees	1	1.60428	12.03508	3.00877	15.04385	7.52192
1b-01	Cocoa + Trees	1	0.98300	24.57509	6.14377	50.72883	25.36442
1b-01	Cocoa	1	0.98300	24.57509	6.14377	30.71886	15.35943
1b-01	Cocoa + Trees	2	0.66104	16.52596	4.13149	40.66742	20.33371
1b-01	Cocoa	2	0.66104	16.52596	4.13149	20.65745	10.32872
1b-02	Cocoa + Trees	1	2.87176	71.79404	17.94851	89.74255	44.87128
1b-02	Cocoa	1	0.94313	23.57816	5.89454	29.47270	14.73635
1b-02	Cocoa + Trees	2	2.97325	74.33136	18.58284	92.91420	46.45710
1b-02	Cocoa	2	2.50530	62.63259	15.65815	78.29074	39.14537
1b-03	Cocoa + Trees	1	2.32826	58.20639	14.55160	72.75798	36.37899
1b-03	Cocoa	1	2.31114	57.77851	14.44463	72.22314	36.11157
1b-03	Cocoa + Trees	2	2.56458	64.11438	16.02860	80.14298	40.07149
1b-03	Cocoa	2	1.11198	27.79960	6.94990	34.74950	17.37475
1b-04	Cocoa + Trees	1	3.39438	84.85959	21.21490	106.07449	53.03724
1b-04	Cocoa	1	2.02149	50.53719	12.63430	63.17149	31.58574
1b-04	Cocoa + Trees	2	2.72880	68.22008	17.05502	85.27510	42.63755
1b-04	Cocoa	2	2.52922	63.23040	15.80760	79.03800	39.51900
1c-01	Cocoa + Trees	1	7.33045	183.26114	45.81529	229.07643	114.53821
1c-01	Cocoa	1	1.54537	38.63428	9.65857	48.29285	24.14642
1c-01	Cocoa + Trees	2	2.66386	66.59656	16.64914	83.24570	41.62285
1c-01	Cocoa	2	0.86225	21.55631	5.38908	26.94538	13.47269
1c-02	Cocoa + Trees	1	7.76314	194.07841	48.51960	242.59802	121.29901
1c-02	Cocoa	1	1.62139	40.53486	10.13372	50.66858	25.33429
1c-02	Cocoa + Trees	2	5.96399	149.09970	37.27493	186.37463	93.18731
1c-02	Cocoa	2	1.90082	47.52059	11.88015	59.40074	29.70037
1c-03	Cocoa + Trees	1	1.77446	44.36157	11.09039	55.45197	27.72598
1c-03	Cocoa	1	1.17881	29.47023	7.36756	36.83778	18.41889
1c-03	Cocoa + Trees	2	3.91221	97.80535	24.45134	122.25669	61.12834
1c-03	Cocoa	2	1.43109	35.77718	8.94430	44.72148	22.36074
1c-04	Cocoa + Trees	1	8.80806	220.20157	55.05039	275.25197	137.62598
1c-04	Cocoa	1	3.41832	85.45807	21.36452	106.82259	53.41130
1c-04	Cocoa + Trees	2	9.56667	239.16673	59.79168	298.95841	149.47921
1c-04	Cocoa	2	1.51704	37.92592	9.48148	47.40740	23.70370
2a-01	Oil palm + Trees	1	16.29965	65.19858	16.29965	81.49823	40.74911
2a-01	Oil palm	1	15.90208	63.60833	15.90208	79.51041	39.75521
2a-02	Oil palm + Trees	1	16.96226	67.84905	16.96226	84.81131	42.40565
2a-02	Oil palm	1	16.31275	65.25101	16.31275	81.56376	40.78188
2a-03	Oil palm + Trees	1	23.08948	92.35793	23.08948	115.44741	57.72370
2a-03	Oil palm	1	20.08076	80.32306	20.08076	100.40382	50.20191
2a-04	Oil palm + Trees	1	18.59136	74.36546	18.59136	92.95682	46.47841
2a-04	Oil palm	1	18.46800	73.87200	18.46800	92.34000	46.17000
2a-05	Oil palm + Trees	1	21.51911	86.07643	21.51911	107.59554	53.79777
2a-05	Oil palm	1	21.51911	86.07643	21.51911	107.59554	53.79777
2a-06	Oil palm + Trees	1	15.52812	62.11247	15.52812	77.64059	38.82030
2a-06	Oil palm	1	15.37024	61.48094	15.37024	76.85118	38.42559
2a-07	Oil palm + Trees	1	18.69998	74.79994	18.69998	93.49992	46.74996
2a-07	Oil palm	1	18.69998	74.79994	18.69998	93.49992	46.74996
2a-08	Oil palm + Trees	1	26.74794	106.99178	26.74794	133.73972	66.86986
2a-08	Oil palm	1	25.79348	103.17391	25.79348	128.96739	64.48370
3a-01	Citrus + Trees	1	7.01381	28.05524	7.01381	35.06905	17.53452
3a-01	Citrus	1	6.65068	26.60272	6.65068	33.25340	16.62670
3a-02	Citrus + Trees	1	27.88473	111.53891	27.88473	139.42364	69.71182

Code	Crop	Rep	AGB/plot	AGB/ha	BGB/ha	Btot/ha	tC/ha
3a-02	Citrus	1	17.56759	70.27036	17.56759	87.83795	43.91897
3a-03	Citrus + Trees	1	13.98570	55.94281	13.98570	69.92851	34.96425
3a-03	Citrus	1	13.82566	55.30265	13.82566	69.12831	34.56415
3a-04	Citrus + Trees	1	18.12381	72.49524	18.12381	90.61904	45.30952
3a-04	Citrus	1	14.07639	56.30557	14.07639	70.38196	35.19098
3a-05	Citrus + Trees	1	13.25289	53.01154	13.25289	66.26443	33.13221
3a-05	Citrus	1	13.20796	52.83186	13.20796	66.03982	33.01991
3a-06	Citrus + Trees	1	10.05214	40.20854	10.05214	50.26068	25.13034
3a-06	Citrus	1	9.61024	38.44097	9.61024	48.05121	24.02561
3a-07	Citrus + Trees	1	32.92091	131.68363	32.92091	164.60454	82.30227
3a-07	Citrus	1	32.72710	130.90842	32.72710	163.63552	81.81776
3a-08	Citrus + Trees	1	10.47462	41.89850	10.47462	52.37312	26.18656
3a-08	Citrus	1	10.01893	40.07573	10.01893	50.09466	25.04733
4a-01	Rubber + Trees	1	0.90219	22.55464	5.63866	28.19329	14.09665
4a-01	Rubber	1	0.90219	22.55464	5.63866	28.19329	14.09665
4a-01	Rubber + Trees	2	5.93095	148.27371	37.06843	185.34214	92.67107
4a-01	Rubber	2	4.55558	113.88942	28.47235	142.36177	71.18089
4a-02	Rubber + Trees	1	2.98958	74.73940	18.68485	93.42425	46.71212
4a-02	Rubber	1	2.98958	74.73940	18.68485	93.42425	46.71212
4a-02	Rubber + Trees	2	2.29500	57.37512	14.34378	71.71889	35.85945
4a-02	Rubber	2	2.13456	53.36400	13.34100	66.70500	33.35250
4a-03	Rubber + Trees	1	1.99607	49.90176	12.47544	62.37720	31.18860
4a-03	Rubber	1	1.98672	49.66794	12.41699	62.08493	31.04247
4a-03	Rubber + Trees	2	2.50932	62.73305	15.68326	78.41631	39.20815
4a-03	Rubber	2	2.50006	62.50161	15.62540	78.12702	39.06351
4a-04	Rubber + Trees	1	2.90051	72.51274	18.12819	90.64093	45.32046
4a-04	Rubber	1	2.90051	72.51274	18.12819	90.64093	45.32046
4a-04	Rubber + Trees	2	4.59920	114.98008	28.74502	143.72510	71.86255
4a-04	Rubber	2	4.59920	114.98008	28.74502	143.72510	71.86255
5a-01	Cedrela + Trees	1	6.65481	166.37018	41.59254	207.96272	103.98136
5a-01	Cedrela	1	3.34068	83.51706	20.87926	104.39632	52.19816
5a-01	Cedrela + Trees	2	9.59958	239.98950	59.99737	299.98687	149.99344
5a-01	Cedrela	2	9.54123	238.53085	59.63271	298.16356	149.08178
6a-01	Ylang ylang + Trees	1	12.05182	301.29538	75.32384	376.61922	188.30961
6a-01	Ylang ylang	1	2.24539	56.13465	14.03366	70.16832	35.08416
6a-01	Ylang ylang + Trees	2	0.75094	18.77348	4.69337	23.46686	11.73343
6a-01	Ylang ylang	2	0.57656	14.41389	3.60347	18.01736	9.00868
7a-01	Black pepper + Trees	1	6.09685	152.42137	38.10534	190.52671	95.26336
7a-01	Black pepper	1	3.77025	94.25629	23.56407	117.82036	58.91018
7a-01	Black pepper + Trees	2	2.67530	66.88253	16.72063	83.60317	41.80158
7a-01	Black pepper	2	1.77778	44.44450	11.11113	55.55563	27.77782
8a-01	Nutmeg	1	0.12019	4.88280	1.22070	6.10350	3.05175
9a-01	Conservation area	1	11.95839	191.33427	47.83357	239.16784	119.58392
9a-01	Conservation area	2	13.24934	211.98948	52.99737	264.98685	132.49343