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COCOA YIELD EVALUATION AND SOME IMPORTANT YIELD FACTORS IN SMALL HOLDER *THEOBROMA CACAO* AGROFORESTS IN BOKITO- CENTRE CAMEROON

BY:

Eltson ETECKJI FONKENG

Thesis presented in partial fulfillment of the requirements for obtaining the diplôme d'Ingénieur Agronome - learing option crop science

DECEMBER 2014

REPUBLIC OF CAMEROON
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CERTIFICATE OF ORIGINALITY

I the undersigned, Eltson ETECKJI FONKENG, testify that the present thesis is the fruit of my personal work carried out within the framework of the SAFSE project at CIRAD (Centre International de Recherche Agronomique pour le Développement) under the supervision of Dr. Ing. Stephane Saj (CIRAD) my internship master and academic supervision of Dr MVONDO AWONO Jean Pierre (Senior lecturer and head of Department of the Department of crop science at the Faculty of Agronomy and Agricultural Sciences of the University of Dschang) and Dr. Beyegue Djonko Honore (Assistant lecturer at the Department of crop science of the Faculty of agronomy and agricultural sciences of the University of Dschang).
This thesis is authentic and has not been previously used in obtaining any university degree or diploma.

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ABSTRACT

Cocoa is one of the five most important cash crops of central and West Africa. Cocoa is inter-cropped with several forest and high value tree species that provide shade to the cocoa tree and additional income and different products for the farmers. This cocoa cultivation system causes minimum damage to the environment as well as providing numerous other advantages when compared to conventional monoculture system. The yields in this agroforestry system in Centre Cameroon and the factors which mostly affect them are reviewed. The aim is to evaluate the yields and highlight the factors governing yields in this system in view of optimising the yields while respecting the environment. This work was carried out from April to October 2014 in the Centre region of Cameroon (one of the main cocoa producing areas in Cameroon) precisely in Bokito sub division.

The approach used in this work consists in randomly selecting 54 samples of dimensions 40 m x 20 m (800 m^2) from already characterised cocoa agro-forest (with respect to age and preceding land occupation) in Bokito in 2013. And on each sample, data on the number of pods (produced, ripe, diseased and destroyed by animals) was collected for yield evaluations. Further data on cocoa population (height, architectural type, diameter at breast height) and associate population (number of fruit trees, tree production per year) was collected for analysis of the management structure and state of cocoa farms.

It was observed at the end of the study that the potential yield on average in Bokito is 819.2 kg/ha and that there was no significant difference of yields with respect to preceding land occupation but there was with respect to the age of the farm. Potential yield also increases significantly with cocoa tree basal area. Potential yield revealed a weak positive relationship with the mean height of cocoa trees and a strong positive relationship with carbon stocks. Pertaining to fruit trees, it was observed that citrus fruits trees appeared on top of the priority list of farmers as companion trees for cocoa when creating their farms. It is concluded that potential yield greatly depends on the structure of the cocoa plants and that fruit trees providing food and a source of revenue other than cocoa is preferred to other trees by the farmers.

RÉSUMÉ

Le cacao est l'une des principales cultures de rente en Afrique Centrale et de l'Ouest. Il est cultivé en association avec plusieurs espèces d'arbres forestiers et d'espèces d'arbres à grande valeur ajoutée qui fournissent de l'ombrage aux cacaoyers et assurent également un surplus de revenu aux producteurs. Ce système de culture du cacao cause moins de dégâts environnementaux et présente de nombreux avantages par rapport au système conventionnel de monoculture. Les rendements dans les systèmes agro-forestiers du centre Cameroun et certains facteurs dont ils dépendent sont étudiés dans la présente étude. L'objectif est d'évaluer les rendements et de faire ressortir les facteurs déterminants dans ces systèmes en vue de leur optimisation agronomique tout en respectant l'environnement. Ce travail a été effectué entre Avril et Octobre 2014 dans la région du Centre Cameroun (un des principaux bassins de production du cacao) précisément dans l'arrondissement de Bokito.

La méthodologie adoptée pour ce travail a consisté à sélectionner de manière aléatoire 54 parcelles de dimension 40 m x 20 m (800 m^2) préalablement caractérisées en 2013 en fonction de l'âge et du précédent cultural dans le cadre d'autres études. Chaque parcelle a fait l'objet de collecte de données sur le nombre de cabosses produites, mûres, pourries et rongées, en vue de l'estimation des rendements en cacao marchand. Des données ont été collectées sur la structure des populations de cacaoyers (hauteur, type architectural et diamètre à hauteur de poitrine) et sur le nombre d'espèces fruitières comprises dans les peuplements associés pour l'analyse des stratégies de gestion des champs par les agriculteurs.

Les résultats montrent que le rendement potentiel en cacao marchand à Bokito est de 819.2 kg/ha et qu'il n'est pas dépendant du précédent cultural mais est fonction de l'âge de la cacaoyère. Il est également démontré que ce rendement potentiel augmente significativement avec la surface terrière des cacaoyers. Une faible corrélation positive entre le rendement potentiel et la hauteur moyenne des cacaoyers a été observée de même qu'une forte association entre le rendement potentiel et le stock de carbone du peuplement cacaoyer. En ce qui concerne les espèces fruitières, il en ressort que les paysans ont une préférence pour les agrumes comme espèces à associer au cacao. En conclusion on peut dire que la structure du peuplement cacaoyer influence largement le rendement potentiel et que ces espèces fruitières fournissent à la fois de la nourriture et sont une source de revenu supplémentaire aux cacaoculteurs.

DEDICATION

This work is dedicated to God almighty for the strength he has given me throughout my life and to the Fonkeng's family for their constant love and support in all my undertakings.

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I must acknowledge the fact that my entire training period has been successful from the beginning to now due to the help of many people to whom I am grateful.

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Chapter 1: INTRODUCTION

1.1 Context of study

Cacao, one of the world's most important perennial crops, is almost exclusively explored for chocolate manufacturing. There are 5-6 million cocoa farmers worldwide. 40-50 million people depend upon cocoa for their livelihood. About 90 % - 95 % of all cocoa is produced by smallholder farmers (World cocoa foundation (WCF), 2010. The typical size of a smallholder farm is about three hectares, with a very large proportion of the farms in the size group of two to five hectares. (WCF, 2010). Most cacao varieties cultivated belong to three groups: Criollo, Forastero and Trinitario that vary according to morphology, genetic and geographical origins. The names Criollo, Forastero and Trinitario indicate the three main types or groups of populations of *Theobroma. cacao* as proposed by Cheesman (1944). The rise in demand for cocoa bean seeds is fiendishly high but production is still not sufficient even with the increase in surface area cultivated. Generally, in West and Central Africa, cocoa is one of the main cash crops cultivated by the local population. West and Central Africa's principal cocoa (*Theobroma cacao* L.) producing countries (in order of importance) are Cote d'Ivoire, Ghana, Nigeria, Cameroon, and Togo (Duguma *et al*, 2001). Among these 5 countries, Ivory Coast, Ghana, Nigeria and Cameroon produce three quarter of the world's production with respectively 1.5 million, 1 million, 0.24 million and 0.29 million tons (ICCO, 2013).

It is estimated that there are over 400,000 households producing cocoa in Cameroon (Losch *et al.*, 1994) but this number is much higher today. Since the late 1980s, the cocoa sector has been subjected to several economic shocks that have led to new institutional and organizational frameworks. This was particularly the case with countries such as Cameroon and Ivory Coast whose economies depended heavily on the cocoa sector. The drastic fall in the world cocoa and other commodity prices at the time contributed to substantial cuts in civil servants salaries, significant (50%) currency devaluation, freezes on employment, tax hikes and a reduction of state employees in both countries (Duguma *et al.*, 2001). Cocoa farmers and many state employees who lost their jobs or faced salary cuts responded to the crisis by increasing their activity in food crop production to compensate for lost income. This in turn led to a very significant increase in forest clearing with its attendant profound negative environmental impacts (deforestation-loss of biodiversity, exposition of soil to erosion-risk of soil fertility loss), economic and political consequences. With the low world prices prevailing over the past years, the economic sustainability of agricultural systems has been put in serious question.

Due to the problems posed by the current economic situation which favoured deforestation and thus loss of biodiversity, the government had to intervene by implementing several structural reforms like the liberalisation of the cocoa sector in 1992 (Duguma *et al.*, 2001) which led to little or no support to local farmers in the cocoa sector. The local people on their part responded to this by crop diversification where they cropped cocoa with food crops as well as tree species. In central Cameroon, cocoa cropping is based on an agroforestry system in which cocoa trees are always grown in association with forest or fruit tree species that farmers preserve or introduce when the forest is felled. Cocoa trees are subsequently planted in the cleared areas (Duguma *et al.*, 2001). For numerous households, diversification of revenue sources appeared to be the survival strategy (Jagoret *et al.*, 2009).

This work takes place within the context of the SAFSE (Recherche de compromis entre productions et services écosystémiques fournis par les systèmes agroforestiers) project hosted by Cirad (Centre International de Recherche Agronomique pour le Développement). To attain its goals, the project is divided into four work packages (WP) each concerning a particular discipline and the working teams on the field.

- WP0: Animation and coordination of the project around a shared conceptual framework.
- WP1: Characterisation of the composition, structure and dynamics of the system.
- WP2: Production services and other ecosystem services in agro-forest systems, interactions and compromises. Our work is based in this work package.
- WP3: Analysis of possible improvements of AFS (agro-forestry systems) through technical and institutional innovations.

The present study is situated in work package 2 and it is carried out in the project after the WP0 and WP1 have been carried out i.e. after animation and coordination of the project around a shared conceptual framework and characterisation of the composition, structure and dynamics of the system and this was done in 2013. Specifically it is in WP2T1-Opération4b-‘evaluation sur le long terme des systèmes agroforestiers à base de cacaoyer installés en zone de transition forêt-savane et impact de leur composition et de leur structure sur la fertilité du sol.' The objectives of this work package 2, task 1, and operation b are:

- analyses in the long run of the transformation of savannahs into complex cocoa based agro-forest systems through the evolution of the composition and structure of the different populations (cocoa and associate productions).
- compare in the long run the evolution of the structure of complex cocoa based agro-forest systems on savannahs to those on forest galleries.
- evaluate the impact of the composition and structure of cocoa based agro-forests systems on the evolution of soil fertility in function of the two preceding vegetation or land occupation (forest and savannah).

1.2 Problem statement

The problem that arises with complex cocoa agro-forestry systems despite all the advantages they have over other production systems is the little or no information available on the actual and potential yield of these systems. The proportion of the potential yield that actually gets to the farmer is not known. So evaluation of the yields in this system is of focal interest and the extent to which certain yield factors affect yields is not properly understood.

Quantifying food production capacity on every hectare of current farmland in a consistent and transparent manner is needed to inform decisions on policy, research, development and investment that aim to affect future crop yields and land use and to inform on-ground action by local farmers through their knowledge networks (Yield gap analysis with local to global relevance). Potential yields are theoretical yields. It is location specific because of the climate, but in theory not dependent on soil properties assuming that the required water and nutrients can be added through management (which, of course, is not practical or cost-effective in cases where major soil constraints, such as salinity or physical barriers to root proliferation, are difficult to overcome) (van Ittersum *et al.,* 2013).

Despite the advantages agroforestry systems have over monoculture systems, production is usually low when we consider only these advantages. This thus prompts the following questions to be asked;

What is the potential and actual yield of cocoa in complex cocoa agro-forest systems in Bokito and how does the age and preceding culture influence these yields.

To answer this question, the following secondary questions are to be answered:

- what is the effect of the age and preceding culture on yield?
- what are the average weight and the number of bean seeds per cocoa pod?

- what is the proportion of pods that reach maturity and are harvested by the farmer?

1.3 Objectives of the study

Generally, the study is designed to optimise the yields in cocoa agro-forests in Bokito. Specifically the study seeks to:

- evaluate both the actual and potential yields of cocoa in the complex agroforestry system in Bokito;
- evaluate the extent to which the potential yields depend on the age of the plants;
- evaluate the extent to which the potential yields depend on the preceding vegetation;
- determine what proportion of potential yields actually gets to the farmer (actual yield).

1.4 Hypothesis of the study

Hypotheses resulting from research questions which were investigated in this study are the following:

- potential yield depends on system's age (hypothesis 1);
- potential yield depends on system's preceding vegetation (hypothesis 2);
- potential yield depends on interaction between age and preceding vegetation (hypothesis 3);
- proportion of the potential yield actually perceived by the farmers depends on the level of the pest and diseases pressure (hypothesis 4).

1.5 Importance of study

Cocoa is a crop of great importance to the local population of Cameroon especially those in the cocoa production basins of the country (Centre, South West and South regions). The economic crisis in Cameroon led to the drop of cocoa prices on the international market and consequently led to decrease in the standard of living of the cocoa farmers.

In Cameroon, farmers opted for an increase in cocoa cropped surface areas and a composition of a multi-usage cocoa farm to make up for loss of revenue due to fluctuations of prices in the market (Zapfack *et al.*, 2002) which in turn has its negative effects on the environment.

On a scientific scale, this study will contribute to the bulk of knowledge on cocoa agro-forests and will serve also as a data base for subsequent research on yield and yield improvements in cocoa agro-forests.

On a local scale, the state and the agricultural extension workers will be able to use the results from the study to develop better policy and advice farmers on better management of their fields to close the yield gap between the potential and the actual yield in their farms. It will also provide information necessary for the creation of new cocoa farms in the region so as to optimise production.

1.6 Limitations of the study

The study could not evaluate fully the actual yields in Bokito due to the fact that farmers were harvesting cocoa pods while the study was going on to satisfy their immediate needs. This has surely contributed to bias estimations made for actual yield. In addition, the study did not take into consideration other food crops. So quantifying the total amount of all other useful produce from cocoa agroforests in Bokito would not be possible with this study.

Chapter 2: LITERATURE REVIEW

Cocoa was introduced into Cameroon by colonial powers in the coastal areas of the country notably in the south west region of the country. Production was mostly done in monoculture plantations. In Cameroon, fifth world cocoa producer, the cultivation of cocoa is mainly done in traditional systems and it represents 91.9% of plantations in 2001 (Durot, 2013). The soils here are highly weathered, deep and leached soils. But today cocoa production is carried out mostly in agroforestry systems. The agroforestry systems in centre Cameroon and south Cameroon are similar in that they are characterised by a great diversity of plants ranging from fruit trees, forest tree species to diverse food crops. This is also noticed in the south west region where cocoa is grown but with lesser diversity of species. This gives it a multi-strata system with different structural arrangements. Because of these, they are termed complex agroforestry systems but more due to the diversity of species encountered. Only a limited proportion of cocoa farms are monoculture due to the fact that most farmers are poor and can't afford the large inputs required for monoculture cropping of cocoa.

Agroforestry is the deliberated introduction or retention of arboreal species and or animals with food crops on the same unit of land. In the transitional area between the forest and the Savannah of Cameroon, Gokowski and Dury (1999) mentioned the existence of fruit tree species such as *Mangifera indica, Persea americana, Dacyrodes edulis, Citrus reticula, Citrus sinensis, Elaeis guinensis, Cola nitida*, and *Irvingia gabonensis*. In a survey conducted in 37 cocoa plantations in Southern Cameroon, Zapfack *et al*., (2002) revealed the existence of 116 plant species. This shows the management system adopted by the local farmers to solve their problems and this is diversification of crops.

The 2010-2011 world harvest was 4.3 million tons (MT) with Africa supplying 74.8% which corresponds to 3.2 MT, revealing a yield increase of 18.5% as compared to the previous year. The harvest for 2011-2012 was lower, 4.011 MT and this due to the drought conditions that prevailed in West Africa this season (ICCO, 2013).West Africa had a decent cocoa crop in 2012/13 (October-September), totalling 2.76 MT, 2% lower than last season, owing to falls in production in Ivory Coast and Ghana. The outlook for the 2013/14 season is troubled, with a drop in fertiliser usage in Ivory Coast and Ghana likely to reduce yields, cutting production for the region to 2.62 MT (Aithnard, 2011). Cameroon in the 2011/2012 season produced 207

000 tons (T) and estimates for the 2012/2013 season was 225 000 T while forecasts for the 2013/2014 season are placed at 210 000 T (ICCO, 2014).

To better understand this work, certain key definitions will be discussed and a general review of cocoa done covering the taxonomy, production and post-harvest handling of cocoa as well as recent research on cocoa yields carried out so far and which we could lay hands on in literature.

2.1 Definitions and characterization of concepts

2.1.1 Agroforestry and agroforestry systems

Agroforestry is any sustainable land-use system that maintains or increases total yields by combining food crops (annuals) with tree crops (perennials) and/or livestock on the same unit of land, either alternately or at the same time, using management practices that suit the social and cultural characteristics of the local people and the economic and eco-logical conditions of the area. Reijntjes *et al.,* (1995).

Baumer (1987) defines an agroforestry system as a technique and mode of land use in which trees (forest component), are voluntarily associated on the same piece of land to food crops and or animals either simultaneously or sequentially. From this definition it can be deduced that there are three main types of agroforestry systems and these are:

- agro-sylvicultural systems (food crops associated to trees)
- sylvo-pastoral systems (trees associated to animals)
- agro sylvo pastoral system (food crops associated to trees and animals)

But according to Foresta and Michon (1993) there are two groups of agroforestry systems which are: simple and complex agroforestry systems. The simple agroforestry systems are those containing a very limited number of species associated while the complex ones are those containing a high number of species associated.

In this study, both Baumer's and Foresta and Michon's definitions are integrated in the view of an agroforestry system.

2.1.2 Chronosequence

A chronosequence (in forest sciences) is a set of forested sites that share similar attributes but are of different ages. Since many processes in forest ecology take a long time (decades or centuries) to develop, chronosequence methods are used to represent and study the time-dependent development of a forest. Field data from a chronosequence can be collected in a short period of several months. For example, chronosequences are often used to study the changes in plant communities during succession.

2.1.3 Biomass

Biomass is the total number of living organisms in a given area, expressed in terms of living or dry weight per unit area or the total amount of living material in a given habitat, population, or sample. Specific measures of biomass are generally expressed in dry weight (after removal of all water from the sample) per unit area of land or unit volume of water.

2.1.4 Biodiversity

Biological diversity, or the shorter "biodiversity," (bio-di-ver-si-ty) simply means the diversity, or variety, of plants and animals and other living things in a particular area or region. For instance, the species that inhabit Yaoundé are different from those in Garoua. Biodiversity also means the number, or abundance of different species living within a particular region.

In practice, "biodiversity" suggests sustaining the diversity of species in each ecosystem as we plan human activities that affect the use of land and natural resources. Maintaining a wide diversity of species in each ecosystem is necessary to preserve the web of life that sustains all living things. In his 1992 best-seller, "The Diversity of Life," famed Harvard University biologist Edward O. Wilson -- known as the "father of biodiversity," -- said, "It is reckless to suppose that biodiversity can be diminished indefinitely without threatening humanity itself." This tells us that to solve most of our problems, we are to conserve as much as possible the biodiversity in our environment.

2.1.5 Climate change

Climate is usually defined as the “average weather condition” in a place for long periods of time. It includes patterns of temperature, precipitation (rain or snow), humidity, wind and seasons. Climate change is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions, or in the distribution of weather around the average conditions (i.e., more or fewer extreme weather events). Climate change is caused by factors such as biotic processes, variations in solar radiation received by Earth, plate tectonics, and volcanic eruptions. Certain human activities have also been identified as significant causes of recent climate change, often referred to as "global warming".

2.1.6 Ecosystem services

Ecosystem services are the actual life-support functions, such as cleansing, recycling, and renewal, and they confer many intangible aesthetic and cultural benefits as well conditions and processes through which natural ecosystems, and the species which make them up, sustain and fulfil human life. They maintain biodiversity and the production of ecosystem goods, such as seafood, forage, timber, biomass fuels, natural fibre, and many pharmaceuticals, industrial products, and their precursors (Daily, 1997).

Ecosystem services can be classified into:

- supporting services: The services that are necessary for the production of all other ecosystem services including soil formation, photosynthesis, primary production, nutrient cycling and water cycling.
- provisioning services: The products obtained from ecosystems, including food, fibre, fuel, genetic resources, bio-chemicals, natural medicines, pharmaceuticals, ornamental resources and fresh water;
- regulating services: The benefits obtained from the regulation of ecosystem processes, including air quality regulation, climate regulation, water regulation, erosion regulation, water purification, disease regulation, pest regulation, pollination, natural hazard regulation;
- cultural services: The non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences – thereby taking account of landscape values.

2.2 Over view of cocoa

2.2.1 Growing cocoa

2.2.2 Origins of cocoa and its spread around the world

The genus Theobroma originated millions of years in South America to the east of the Andes. All the species of this genus originate from the humid tropical forests in the equatorial Americas where they are exploited and used in the kitchen and in the production of refreshing drinks (Mossu, 1990). Theobroma has been divided into twenty-two species of which T. cacao is the most widely known (ICCO, 2013) and according Mossu (1990), it is the only specie commercially cultivated for grain production destined for the production of chocolate or the extraction of cocoa butter. It was the Maya who provided tangible evidence of cacao as a domesticated crop. The Aztec culture, dominant in Mesoamerica from the fourteenth century to the Conquest, placed much emphasis on the sanctity of cacao (ICCO, 2013). They attributed the divine origin of cocoa to the serpent God '*Quetzacoalt*' and in the sacrifices offered to the god the cocoa drink used was called '*xocoatl'* from which originates the name chocolate. This may be the reason why Carolius Linnaeus (the father of modern taxonomy) named cultivated cocoa *Theobroma cacao L*. after the Greek words for god Theos, and Broma which means food and translated to English gives 'food for the gods'.

From the equatorial Americas, cocoa spread to the other parts of the world, first to Europe by Herrnan Cortés, leader of an expedition in 1519 to the Aztec empire, who returned to Spain in 1528 bearing the Aztec recipe for xocoatl (chocolate drink) with him. It then was introduced to Spain from where it spread throughout Europe. In Africa, Amelonado cacao from Brazil was planted in Principe in 1822, Sao Tomé in 1830 and Fernando Po (today Malabo) in 1854, then in Nigeria in 1874 and Ghana in 1879. There was already a small plantation in Bonny, eastern Nigeria established by Chief Iboningi in 1847, as well as other plantations run by the Coker family and established by the Christian missions. The seeds planted in Ghana were brought from Fernando Po by Tetteh Quarshie or his apprentice Adjah, after previous attempts by the Dutch (1815) and the Swiss (1843) to introduce cocoa in Ghana had failed. In Cameroon, cocoa was introduced during the colonial period of 1925 to 1939 (ICCO, 2013).

2.2.3 Recent research information on cocoa

The relatively low productivity of cocoa in most cocoa producing countries and Cameroon in particular could be attributed to a number of reasons, including poor farm maintenance practices, planting low-yielding varieties, the incidence of pest and diseases, decline in soil fertility, inconsistency in rainfall pattern and non-adoption of improved technologies. Cocoa agro-forest is the intercropping of cocoa trees with fruit, commercial or non-commercial timber, or fast-growing and high-value tree species as well (Duguma *et al.*, 2001). The adoption of environmentally sound and sustainable cocoa production through cocoa agro-forest has been suggested as a useful technology to improve cocoa yields in Ghana, and other cocoa producing countries where marginal lands are increasingly being brought under cultivation (Asare, 2005; Boateng, 2008). Savannah's, thus have lower production aptitudes than forest zones case of central Cameroon where savannahs are increasingly being transformed into cocoa agro-forests. Up till date due to the diversity and complexity of such a technological package and also due to the fact that there is a great variation in environmental and socio economic conditions of the areas where cocoa is cultivated and those who farm cocoa, there is little information available on the yield level of this system of farming.

In Cameroon, there are three main cocoa producing regions which are, the Centre, South, and Southwest regions. Cocoa agroforestry systems in Cameroon have existed for a very long time and have evolved with time, so in evaluating the yields of this system, emphasis has to be placed on the age of the farms so as to be able to study the long-term dynamics of yields in this system as such chronosequential study of this system is necessary.

In Cameroon, Losch *et al*., (1991) report yields of 300 kg/ha under slight shade conditions. According to Jagoret *et al.*, 2011, in Bokito, 45% of the cocoa plantations are 40 years old and cocoa growing had mainly begun developing in the 1950. He also registered a yield of 326 kg/ha of dry cocoa in Bokito but on average for the central region he reported fermented dried cocoa yields of 255 kg/ ha. It is worth noting that the potential yield of cocoa in the forest transition zone in central Cameroon increases with the age of the farm with an increase from 424 kg/ha of dry cocoa bean to 888 kg/ha in farms created on savannah and from 421kg/ha to 733 kg/ha in farms established on forest galleries (Jagoret, 2011) this shows that managing strategies adopted by farmers have transformed savannah's into cocoa production zones and this challenges the cocoa expert's view that savannahs have low production potential for cocoa .

As of fruit trees, in the southern region of Cameroon, *Dacryodes edulis, Irvingia gabonensis* and *Ricinodendron heudelotii* can produce 1.5, 0.65 and 1.87 units per tree and a bag of these fruits weighs 68, 56 and 84 kg respectively (Ndoye, 1995). In the cocoa-based agroforestry systems in the forest transition zone in Cameroon, Massein G., 2000 reports a possible production of 140 and 130 kg of fruits per tree for *Persea americana* and *Mangifera indica*. One of the reasons why farmers keep on growing cocoa in this multispecific system in Centre Cameroon is that they can sell the fruits from the associated trees (which are a source of revenue other than cocoa) and also, the fruits are used for improving on the personal and family diet.

Cocoa cultivation is advised by research to be done after clearing of forest and should be done under no shade as monoculture or under slight shade. But when cocoa is cultivated without shade, its optimum productivity can be obtained only if all other environmental factors are favourable: availability of mineral elements in sufficient quantities, regular supply of fertilizers, well distributed rainfall, protection against mirids (Braudeau, 1969). If not, the absence of shade on the contrary has a depressive effect on the yields which are satisfying in the short run but strongly decrease with time (Ahenkorah *et al*., 1974; Jadin, 1992).

Clayey soils with a good amount of organic matter are most suitable for cocoa production (Mossu, 1990) and Jagoret *et al*., 2012 confirms Mossu's prescription by adding that sandy clayey soils with over 3% organic matter in the top soil are most suitable for cocoa production. Further, according to Jagoret *et al*. (2012) Bokito (Mbam and Inoubou division, centre region of Cameroon), our study site: forest transition zone is characterised by soil and climatic conditions not favourable for cocoa cultivation. Bokito has an annual rainfall of 1300-1500mm/year (Jagoret *et al*, 2009(1)) which is well below the required amount of rainfall needed by the plant per year. Also, bokito has a dry season exceeding 3months with rainfall under 70mm which leads to tree death under monoculture conditions (Jagoret *et al.*, 2009(2)). Again according to Jagoret *et al* (2011) the annual average temperature of Bokito is 25 ºC and the soils are slightly desaturated soils. But surprisingly farmers in this region are establishing cocoa farms on savannah's which are not recommended by scientist and they have been growing cocoa trees for a long time which seems to be an innovation that challenges the expert advice of cocoa agronomist (Jagoret *et al*., 2012). This leaves us to believe that these agroforestry systems are sustainable systems. Presumably, enhanced production in these systems when compared to monoculture systems result from improved resource status associated with common agroforestry processes; efficient nutrient cycling, improved soil characteristics, modified light infiltration, enhanced moisture availability and reduced weed competition (Ahenkorah *et al*, 1987; Hartemink, 2005).

Like most other African countries, the local farmers here produce with little or no farm inputs since they have low access to inorganic fertilizers and pesticides. Multistrata planting schemes integrating both upper canopy trees and cocoa (*Theobroma cacao* L.) are purposefully developed by farmers to diversify farm products, secure land tenure, provide shade for cocoa seedlings and increase biophysical advantages like improvement of soil fertility for production (Isaac *et al*., 2007), control of insect attacks on crops and reducing the incidence of diseases and many others.

Agroforestry systems have some draw backs like the fact that the too much shade they provide may favour the development of diseases. Also, the amount of competition is very high which may have negative effects on the development and growth of cocoa. But even if shade may compete for growth resources, they reduce the stress of coffee (*Coffea spp*.) and cacao (*Theobroma cacao*) by ameliorating adverse climatic conditions and nutritional imbalances. For example, shade trees buffer high and low temperature extremes by as much as 5 °C and can produce up to 14 Mg $ha^{-1}yr^{-1}$ of litter fall and pruning residues, containing up to 340 kg N $ha^{-1}yr^{-1}$(Beer *et al.*, 1998). Tree species can influence biogeochemistry through variation in the quantity and chemistry of their litter, and associated impacts on the soil heterotrophic community (Reich *et al.*, 2005) thus they offer numerous advantages as compared to monoculture systems.

2.2.4 Ecology of cocoa

Soil-climate requirements for cocoa cultivation

Climate factors

Climate is considered as all meteorological phenomena and environmental conditions that directly influence the life of the cocoa tree. The main factors are: Temperature: Cocoa plants respond well to relatively high temperatures, with a maximum annual average of 30 - 32ºC and a minimum average of 18 - 21ºC and Rainfall: Cocoa trees are very sensitive to a soil water deficiency. Rainfall should be plentiful and well distributed throughout the year. An annual rainfall level of between 1,500mm and 2,000 mm is generally preferred Braudeau, 1969). Rainfall less than 100mm per month should not exceed three months if not the growth and productivity of the tree is fiendishly compromised. The above two factors account for the relative humidity of the environment. Cocoa tress love very high relative humidity and the optimum is often as much as 100% during the day, falling to 70-80% during the night.

Soil conditions

Cocoa needs a soil containing coarse particles and with a reasonable quantity of nutrients, to a depth of 1.5 m to allow the development of a good root system. Below that level it is desirable not to have impermeable material, so that excess water can drain away. Cocoa will withstand waterlogging for short periods, but excess water should not linger. The cocoa tree is sensitive to a lack of water, so the soil must have both water retention properties and good drainage.

Chemical properties

The chemical properties of the topsoil are most important, as the plant has a large number of roots for absorbing nutrients. Cocoa can grow in soils with a pH in the range of 5.0-7.5. It can therefore cope with both acid and alkaline soil, but excessive acidity (pH 4.0 and below) or alkalinity (pH 8.0 and above) must be avoided. Cocoa is tolerant of acid soils, provided the nutrient content is high enough. The soil should also have a high content of organic matter: 3.5% in the top 15 centimetres of soil. Soils for cocoa must have certain anionic and cationic balances. Exchangeable bases in the soil should amount to at least 35% of the total cation exchange capacity (CEC), otherwise nutritional problems are likely. The ratio 1:5.is the optimum total nitrogen / total phosphorus ratio recommended.

2.2.5 The plant

The cocoa plant is a dicotyledonous plant. It can attain a height of 12-15 m in its wild state but in domesticated conditions due to planting densities used, it attains a height of 5-7 m (Mossu, 1990).

Roots

It shows a growth dimorphism at the root level with orthotropic growth (the tap root) and a lateral growth (the lateral roots). The roots develop in the 30-50 cm depth of soil and this zone is called the rooting zone. (Mossu, 1990).

Trunk, Jorquette and secondary branches

The trunk is characterised by growing vertically (orthotropically), with a 3/8 phyllotaxy arrangement of leaves with long petioles, the development of orthotropic axillary buds, a well-defined growth pattern and a differentiation of normally five plagiotropic buds from below the apex when the terminal bud degenerates. These buds develop into five branches called the Jorquette.

The branches of a cocoa tree are characterised by: a sub-horizontal (plagiotropic) or horizontal habit, a 1/2 leaf arrangement i.e. the leaves are alternate on both sides of the stem with leaves on short petioles, plagiotropic axillary buds (with some few exceptions) and an ill-defined growth pattern with discontinuous flushes (Mossu, 1990).

Leaf

The leaves occur on tree trunks or during flushes on branches. The leaves are simple, oblong, pointed and veined like a feather. On average the leaves are 20 cm long and 8-10 cm wide but depending on the cultivar and exposure to light the leaf can reach 50cm long. Also those exposed to light are thicker and stronger than shaded leaves.

Flowering and fruiting

Flowers appear at 2 years for precocious species and 3-4 years after germination. Flowers are grouped in inflorescences which develop from axillary buds. Inflorescences appear each year on the same site and produces pronounced swellings called flower cushions. The flowers are small (0.5-1 cm in diameter) regular and pentamenous and generally white or tinged with pink (Mossu, 1990). Only 1-5 per cent of the flowers are successfully pollinated to produce a pod (Wood and Lass, 1985).

As of pollination, it has to be done in the 48 hours proceeding opening of the flowers. Cocoa is insect pollinated. The most important group of pollinating insects are midges belonging to several genera of the family Cera- topogonidae. (Winder, 1977).

The fruit

This is the point of interest in the cocoa plant because it contains the commercial part of the plant. The fruit starts developing three days after pollination when the flower is in the swollen ovary stage. At the early stage, it is called a cherelle and grows to become a pod and attains maturity after 5-6 months depending on the origin. The fruit is attached to the trunk or branch by a woody stalk. The pericarp of the pod is made up of three parts which are; the hairy and thick epicarp with an epidermis which is often pigmented, the mesocarp which is thin, hard and more or less woody and the hairy endocarp which is of varying thickness.

Pods generally contain an average of thirty to forty seeds. This can be used in giving a rough estimate of yield of the plantation. The pod contains a single cavity in which the seeds, surrounded by a thick mucilaginous pulp, appear to overlap one another in five longitudinal rows. But the numbers of seeds per pod varies enormously and according to the institute de recherché du café et du cacao (IRCC), there are four main factors responsible for this variations and they are:

- the level of pollination (effective deposition of pollen on the styles of flowers).
- the average number of ovules in the ovaries (depends on type of cocoa and it represents the potential to produce seeds).
- fertility (the number of fertilised ovules which develop into seeds.
- the minimum number of seeds necessary for a cherelle to remain actively growing (Mossu, 1990). These are thus some of the reasons that could be used to explain abortion of fruits.

As concerns the seed morphology, the seeds when fresh have average dimensions of 20-30 mm in length, 12-16mm wide and 7-12mm thick. After the pulp and outer husk has been removed, the seed generally weighs 1.3-2.3g and after drying, the same seed weighs between 0.9-1.5g. The weight of the dried cotyledon is generally 65% of the weight of the fresh cotyledon but this figure may vary from 50-85% (Mossu, 1990). The shape size and colour of pods depend on the type of cocoa and this is described in the paragraph below.

2.2.6 Cocoa tree varieties (cocoa bean types) or cocoa groups

Generally, bean size, flavour, colour, and chemical composition of the fat, vary considerably in beans of different origins. Traditionally, there have been two main types or groups of cocoa described: Criollo and Forastero.

Criollo

Criollo (*Theobroma cacao* var cacao) means native. It is native to southern Mexico to South America, north and west of the Andes. Fruits are oblong to ovoid in shape and have five to ten longitudinal ridges. The seeds are yellowish white. Criollos dominated the market until the middle of the eighteenth century, but today only a few, if any, pure Criollo trees remain (ICCO, 2013). They are very sensitive to diseases and this could be the possible reason for their abandon. The principal types are the Pentagona or Logarto cacao with a polygonal shape, the Real cacao and the Porcelano cacao (Mossu, 1990). They are used in the chocolate industry for the production of luxury products due to their low bitterness and powerful and pleasant aroma.

Forastero

Forastero is a large group containing cultivated, semi-wild and wild populations of which the Amelonado populations are the most extensively planted. Large areas of Brazil and West Africa are planted with Amelonado. Amelonado varieties include Comum in Brazil, West African Amelonado in Africa, Cacao Nacional in Ecuador (ARIBA) and Matina or Ceylan in Costa Rica and Mexico (ICCO, 2013), Maranhao, comum and Para cacao with the last two resulting from mutation of white cotyledon cacaos Almeida and Catongo (Mossu, 1990).

Trinitario

They are descended from a cross between Criollo and Forastero. Trinitario planting started in Trinidad, spread to Venezuela and then to Ecuador, Cameroon, Samoa, Sri Lanka, Java and Papua New Guinea (ICCO, 2013). They have an intermediary quality between criollos and forasteros as well as intermediary characteristics. The cultivated types mostly used today where selected in Trinidad which explains the name trinitario. The trinitario cultivars often carry the name of the institution where they were selected for example: ICS (Trinidad Imperial College selection), UF (United Fruit selection in Costa Rica), SNK (Nkoemvone selection in Cameroon) (Mossu, 1990).

2.2.7 Pests and diseases of cocoa

Mirids are the major insects that affect cocoa worldwide. The most common species in West and central African countries are *Distantiella theobroma* and *Sahlbergella singularis*. In

South-East Asia the *Helopeltis spp*. is responsible for the damage related to mirids while *Monalonion* species are present in South and Central America. Mirid damage alone, if left unattended for three years, can reduce yields by as much as 75% (ICCO, 2014). Cocoa mirids with their piercing and sucking mouthparts pierce the surface of cocoa stems, branches and pods, killing the penetrated host cells and producing unsightly necrotic lesions by sucking sap. Mirids feeding on shoots often result in the death of terminal branches and leaves, causing dieback. Mated female mirids lay up to 60 eggs that are embedded in the bark of stems forming cankers or inside the pod husk. Another important cocoa pest is the Cocoa Pod Borer (CPB), also known as Cocoa Moth, it is the insect *Conopomorpha cramerella* and it causes damage by perforating the pods.

As concerns diseases, the most common and most destructive are fungal and they include the;

- black pod or phytophthora pod disease caused by the fungus *phytophthora spp*, with the most common specie in Cameroon being *P megacarya*.
- charcoal pod rot caused by the fungus *Botryodiplodia theobromae.*
- mealy pod rot caused by the fungus *trachysphaera fructigena.*

There are many others which cause severe damages in different parts of the world but these are the most dangerous in west and central Africa. They cause damages on the pods decreasing the bean seed quality. Disease causes 21% of potential world production losses and pests cause 25 % losses (Mossu, 1990). As for their control, there are a wide variety of cultural methods of control and a wide range of chemicals to use in controlling pests and diseases.

2.2.8 Planting material

Generally, the selection criteria used to collect the cocoa plant are the plant vigour, precociousness, productivity, the size and quality of the bean and the resistance of the clone to pests and diseases. Selection is carried out following progressive stages: the establishment of a selection, the selection of clones from this collection, hybridisation, and evaluation of interlineal descendants then distribution. Once the interlineal descendants accepted, they are distributed and this can be done by the establishment of cocoa seed farms from where pods will be gotten and can be used to create a nursery for putting in place a plantation. Also, they can be distributed through vegetative multiplication of selected hybrids through multiplication techniques like grafting (lateral and cleft grafting) or budding (chip budding).

2.2.9 Establishment of a cocoa farm

This involves several steps and operations which when clearly respected will lead to a farm which will be less prone to production risks. The most important are the following: Production of seedlings, choice of the planting site, land preparation, establishing temporary shading, protecting the ground with cover crops or food crops like *Flemingia macrophylla, crotalaria spp* or *cetrosoma pubescens*, establishing permanent shading if selected forest species left did not suffice or if all were felled, dig planting holes, planting, maintenance operations: (Mossu, 1990).

2.2.10 Uses of cocoa

The part of the cocoa plant that is used is the pod. After harvesting it, the seeds in the pods is removed, fermented and dried and are thus called cocoa bean seeds. It constitutes the raw material of important agro-industries which manufacture:

Semi-finished products intended for other industries like cocoa mass used in making chocolate, biscuits and confectionery; melted cocoa used in making sweet products in the food industry and cocoa butter used in making sweets, chocolate, perfume, and in pharmacy.

Finished products intended directly for consumption like bars of chocolate, chocolate confectionery and chocolate powder.

By-products from these industries like fats extracted from germs and husks are used in manufacturing fertilizers, pharmaceutical products, and soaps and in making cattle feed.

2.2.11. Harvesting and post-harvest processing

Harvesting

This operation consists in detaching the ripe cocoa pods from the mother plant. After formation of flowers and appearance of the cherelle, five to six months generally are required for pod to reach maturity and it changes colour when ripe. The green pods turn yellow and the red pods turn orange. Once ripe it should be harvested. The pods are harvested by sharply and neatly cutting the stalk of the pod with a sharpened blade e.g a sharp knife or a machete. If the trees are tall, a hook like tool attached to a handle is used in cutting the pod stalk. Harvesting is advised to be done at a regular interval of ten to fifteen days. During harvesting, care should be taken not to destroy the flower cushion which will carry future pods and the tree trunk should also not be wounded so as not to create entry ports for opportunistic fungi.

Fermenting

The traditional process in West Africa, the world's largest cocoa growing area, is simple: Farmers place the pulp-covered beans on the ground, cover them with layers of leaves (often banana), and allow the heap to remain for four to seven daysdepending on the variety of the bean. The length of fermentation varies depending on the bean type, Forastero beans require about 5 days and Criollo beans 2-3 days (ICCO, 2014). It is preferable to mix the heap every two days so that the bean mix ferments evenly. The temperature is raised to 40ºC - 45ºC during the first 48 hours of fermentation (ICCO, 2014). As a general rule, the closer to 50 ºC, that fermentations reach, the better the quality of the dried cocoa is (Anonymous, 2006).Other fermentation methods include; basket and box fermentation. The fermentation is critical for the future development of colour and flavour of the cocoa, although there are still many unknowns as to the exact processes occurring. Development of aroma precursors is essential to the eventual creation of flavours.

Drying of cocoa

Drying of cocoa is an important step in cocoa processing. Some of the reactions which produce good flavoured cocoa are still proceeding during the drying process. Ideally, cocoa should be dried over a five to seven day period or more depending on the type of drying. This allows acids in the cocoa to evaporate off and produce a low acid, high cocoa flavoured product. According to Mossu (1990), there are two main types of drying methods which are;

Natural drying which is drying of the bean seeds using the sun in regions where climates permit and it can be by drying on matting, by the drying 'autobus' and by the movable roof dryer.

Artificial drying which is drying done in regions with climatic conditions preventing sun drying methods. This method uses different heat sources to dry cocoa and there are three main types according to him which are; the simple dryer, the mechanical dryers and the automated workshops all of which use hot air blown over the bean seeds in drying them.

It should be noted other drying methods are being developed today like the solar dryers using specially made polythene bags for concentrating heat from the sun on the bean seeds. This is well developed in Vietnam.

Chapter 3: MATERIALS AND METHODS

3.1 Study site and sampling

The study is carried out in the months of April to October 2014 in the centre region of Cameroon precisely in Bokito. Central Cameroon is located between 2.1° to 5.8° N and 10.5° to 16.2° E, at 600-800 m elevation. The climate is hot and humid, with an average annual temperature of 25°C. It is divided into two distinct wet and dry seasons that vary in duration from north to south (bimodal rainfall regime).Bokito (Mbam and Inoubu Division) is located between 4°35’N; 11°8’E. The average total annual rainfall is around 1,400 mm in Bokito and the main dry season lasts 5 months (mid-November to mid-April). It is located in the forest-savannah transition zone where there is low land pressure (29 inhab. Km^2), characterized by a patchwork of forest galleries and herbaceous and sedge savannahs on rejuvenated slightly desaturated soils (Santoir and Bopda, 1995). In Bokito, the cultivation of cocoa is exclusively carried out by the autochthones of the Yambassa ethnic group (Jagoret, 2011).

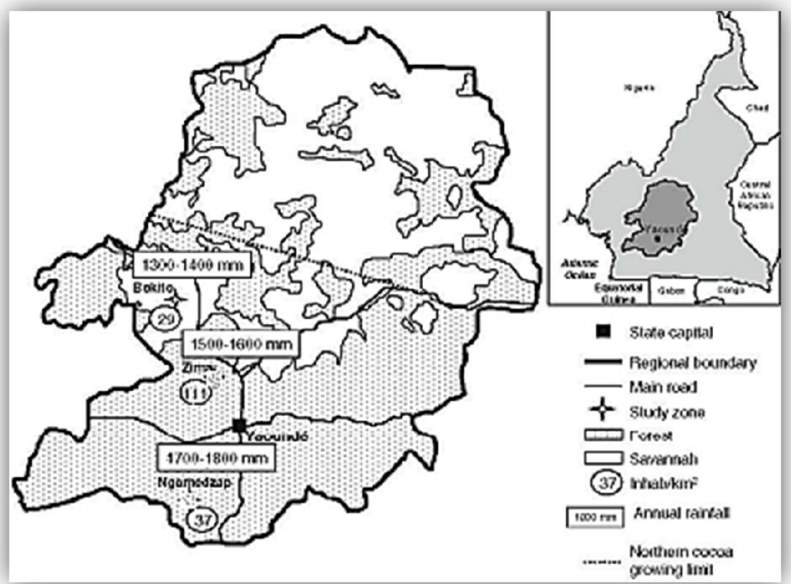

Figure 1: Localisation of study zone

Source: Jagoret et al, 2009. Modified by author

In the study site, this study takes place after the work of Durot (2013) which consisted in characterisation and evaluation of carbon stocks in a network of farms she put in place. From the network of farms 54 cocoa agro-forests (each bearing an attributed number) belonging to 44 farmers (i.e. some individual farmers cropped several cocoa agro-forests) are selected randomly from lists of farmers belonging to local cocoa growers' organizations. The farms are chosen such that there is a representation of each growth stage in the evolution of a cocoa based agro forest system. There is thus a chronosequence of five different age groups i.e. ≤ 10 years (young cocoa just getting into production), 10<age≤20 (mature cocoa in full production), 20<age≤40 (mature cocoa susceptible to yield declines), 40<age≤60 (senescent cocoa susceptible to yield declines) and > 60 years (senescent cocoa) established on two different precedent vegetation (forest and savannah).

Table 1: Number of fields sampled with respect to age of farms and precedent vegetation.

	Age categories					**total**
Plots/Age	≤ 10	10<age<20	20<age<40	40<age60	> 60	-
Forest	8	2	7	7	2	26
Savannah	2	6	5	5	10	28
Total	10	8	12	12	12	54

The study in these farms is done in rectangular sample plots of 800 m^2 (20 m x 40 m). These are homogeneous plots defined as being a portion of an area where cocoa tree stands have a uniform age and structure. Rectangular because according to *Hairiah et* al (2011), rectangular sample plots cover more heterogeneous zones and as such is more representative of the sample population than sample plots of square or circular shape of the same surface area. He used rectangular sample plots in his study of dimensions 20 m x 10 m. Since the larger the sample the more precise the data from the sample, sample plots of higher dimensions than he used are used in this study. Below is a schematic representation of a sample plot.

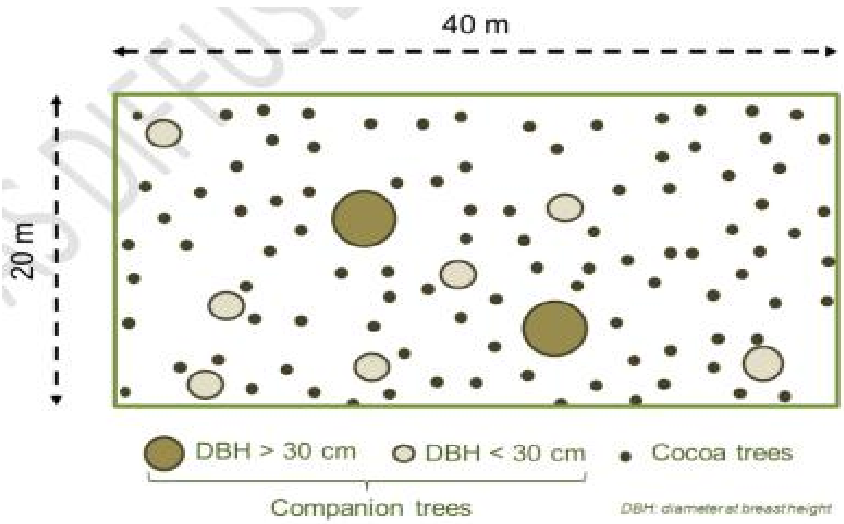

Figure 2: Schematic representation of sample plots

In any scientific work, data has to be collected for analyses in order to attempt answering the questions posed. There are two main types of data to be collected and these are primary and secondary data.

3.1.1 Secondary data

This is data collected from already carried out research work or from any literature relevant to the actual research work being carried out. The secondary data collected for this study is from the university library of the University of Dschang, from the CIRAD library, from IRAD-Nkolbisson library and from scientific publications from the internet.

3.1.2 Primary data

This is data collected on the field. Our primary data is collected in four phases within the period ranging from April to October 2014. In collecting this data, the following equipment is used:

- a GPS (Garmin) for geographical localisation of farms and measuring of their surface areas.
- a bicoloured tape (white and red) for marking the limits of sample plots each time data collection is done.
- a 60 m (Mark: Stanley) and a 5 m long measuring tape for measurements on the field.
- data collection sheets for data recording.
- a graduated ruler for measuring the height of cocoa tress.
- a venial calliper for measurement of cocoa tree diameters.
- paint (of different colours) for marking counted cocoa pods.
- a bamboo stick with a piece of foam tied at its tip used for marking cocoa pods.
- spray markers for marking trees in the sample plot.
- plastic rings, indelible markers and hard white carbon paper for attaching labels on the selected sample cocoa trees.
- a sensitive and high precision measuring balance (Mark: Tristar) for taking the weight of pods and bean seeds.
- a digital camera to taking illustrative photos.

3.2 Methodology

3.2.1 Evaluation of yields

3.2.1.1 Potential yield evaluation

Potential yield is defined as the maximum attainable yield per unit land area that can be achieved by a particular crop cultivar in an environment to which it is adapted when pests and diseases are effectively controlled and nutrients are non-limiting (Evans, 1993). Potential yield is location specific because of the climate, but in theory not dependent on soil properties assuming that the required water and nutrients can be added through management (which, of course, is not practical or cost-effective in cases where major soil constraints, such as salinity or physical barriers to root proliferation, are difficult to overcome) Ittersum *et al,* 2013.

In order to evaluate this yield, a methodology that has already been partially used and published is used in this study. The yields are evaluated in a sample surface area of 800 m^2 (40 m x 20 m) already characterised in 2013 in selected farms. This methodology thus consists in counting and marking cocoa pods which are 10 cm in length and above on all trees in the sample plot. This is done at regular intervals (every six weeks) throughout the production season. This method necessitates a high level of concentration and perseverance on the field.

Once on a sample plot, the following operations are carried out:

- the sample plot is delimited with the help of a white and red coloured tape.
- the geographical coordinates of the plot are taken and recorded with the help of a GPS. This done only once.

All cocoa trees in the plot are checked for a spray mark on them. If the mark is no longer very visible, it is reinforced or if it has been wiped off, a new mark is put.

The potential yield (Yp) of cocoa is expressed in kg of commercial cocoa ha^{-1} and it depends on the average number of cocoa pods per tree and also on the planting density. From these two yield components, it is possible to explain the differences in cocoa yields and to identify the characteristics and cultural practices in the agro-forest systems of Bokito which could be at the origin of the yield differences observed if there are any. The total number of pods per plot is determined by counting the number of fruits (with a length of more than 10 cm) per tree in the plot. According to Lachenaud, 1991; and Bos *et al*, 2006, pods with a length of more than 10 cm are no longer susceptible to be affected by physiological wilt. Because of this, it is hypothesize that all pods of length superior to 10 cm will attain maturity. The total number of pods of the cocoa population is calculated thus by summing the total of all the four field trips during which the pods where counted in each plot.

The counting is done following the illustrative sketch below:

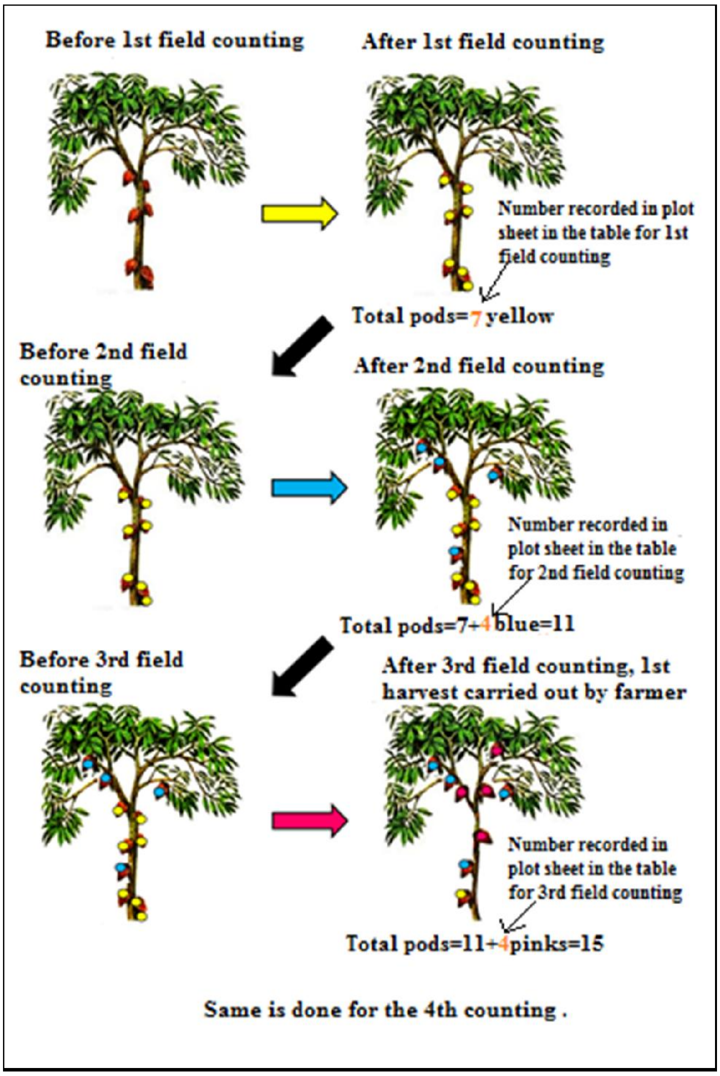

Figure 3: Schematic representation of the method of pod counting.

The weight of the beans in pods and the weight of a pod is gotten from 200 pods randomly harvested throughout the 54 plots. The pods are harvested, weighed and broken. The number of normal bean seeds is counted and weighed. The number of abnormal bean seeds is also counted. All this information is recorded in a data sheet.

The commercial yield of cocoa ha^{-1} is thus calculated from the formula:

Yp= (TNbpod x MFW x TC) x 10000/800

Where

Yp: potential commercial cocoa yield (kg/ha)

TNbpod: total number of pods per plot

MFW: mean fresh weight of beans in one pod (kg)

TC: transformation or drying coefficient

TNbpod x MFW x TC= potential yield of field ($Yp_{(field)}$).

3.2.1.2 Actual yield evaluation.

This is done by systematically choosing 16 living cocoa trees as illustrated by the figure below;

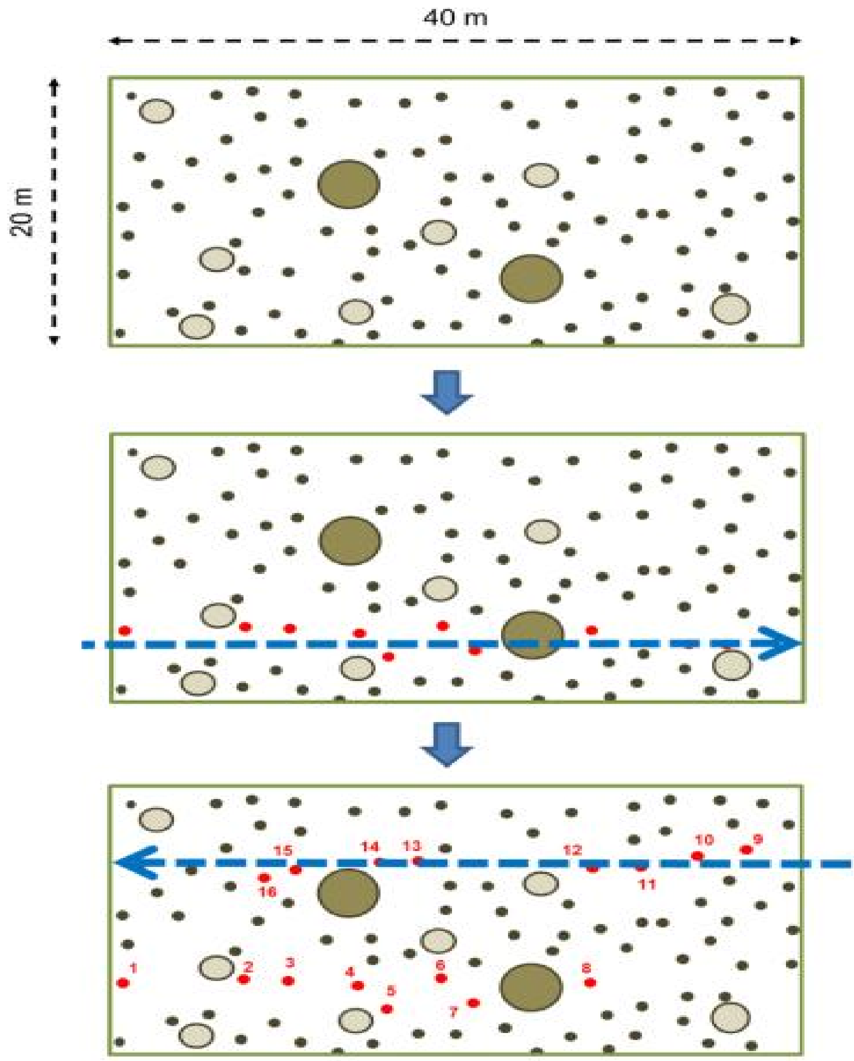

Figure 4: Method of systematic selection of 16 sample cocoa trees.

On the width (20m side), 5m is measured from one corner of the 800 m^2 plot and a white and red tape is attached at the point measuring 5m then the tape is extended along the length to the other side of the plot as shown by the blue dashed arrow on the diagram. The closest trees to the tape are tagged with a number written on a white hard carbon paper using a plastic ring. Once 8 trees have been tagged, one stops and begins the same operation from the other end moving in opposite direction to first tape and another series of 8 trees are selected and tagged as well. If after doing this, not up to 16 trees which are close to the tapes are selected, another 5m is measured again from the first tape moving to the centre of the 20m side. From this point, the tape is stretched as before and cocoa trees are selected till 16 cocoa trees are registered. This is done so as to cover at least 80% of the sample plot area.

Once the sixteen cocoa trees have been selected, the following operations are carried out:

- a label carrying a number between 1 and 16 is put on the cocoa trees.
- measure the breast height diameter of each tree (1.3m).
- take down the number of stems the tree has
- measure the height of the tree.
- describe the architecture of the tree. (Figure 8)

These 16 trees are going to help in evaluating the number of pods produced which reached maturity (actual yield). Since these 16 trees entered into the potential yield evaluation, the total number of pods produced on them is already counted. Now back to those 16 trees the number of ripe pods on them is counted and marked. The number of ripe pods is recorded in the cocoa tree sheet (Annex 2) and the number of ripe healthy pods is recorded (Hpod), the number of ripe but rotten pods is recorded (Rpod) as well as the number of pods eaten by rodents (Epod). This will be used in determining the number of pods produced by the tree which reach maturity and which biotic factor causes more loss of yield. The actual yield then of each plot can thus be determined. The procedure for carrying out this operation is described by figure 6.

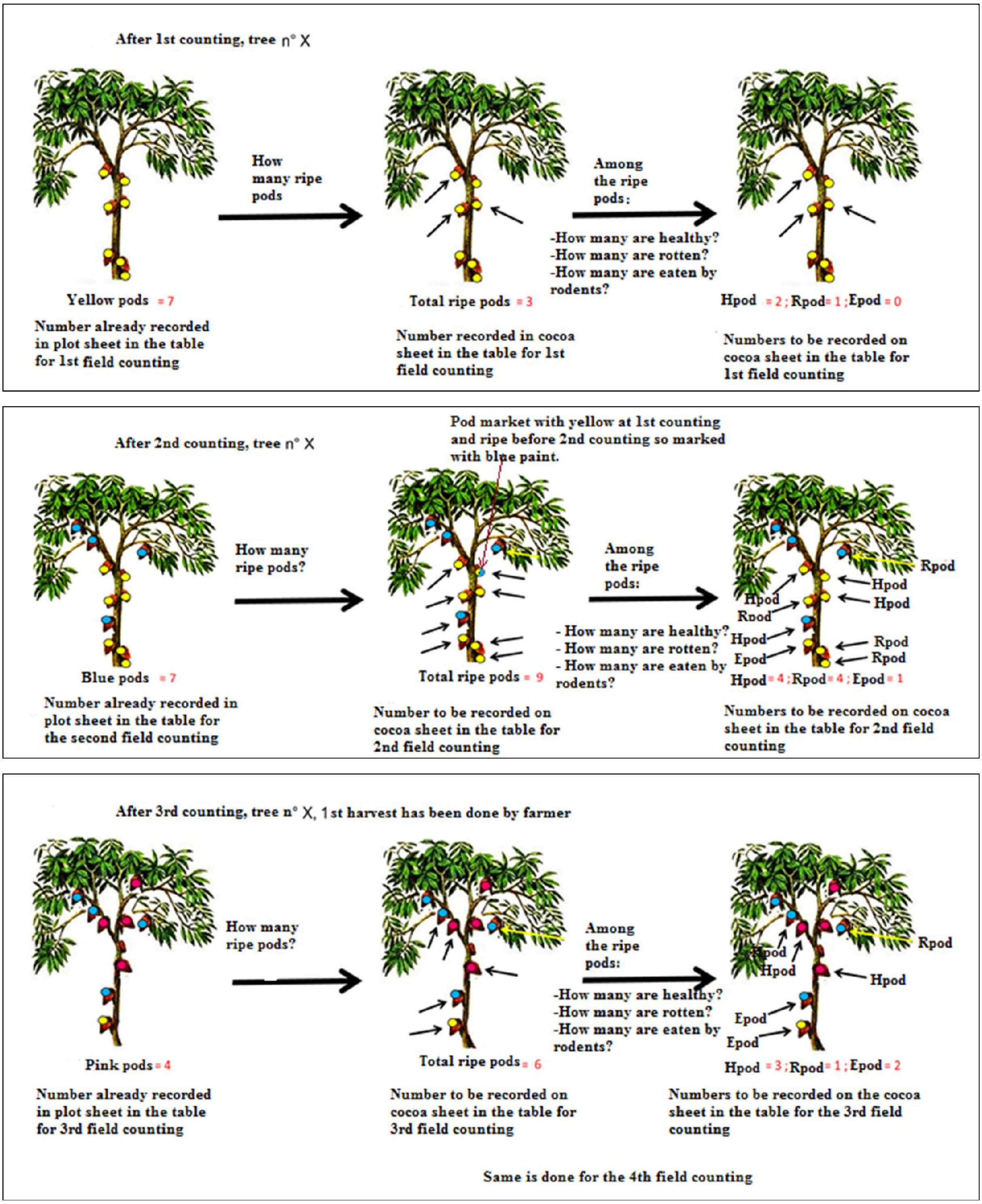

Figure 5: Schematic representation for evaluation of damaged pods.

When a pod is marked in the 1st counting period and it ripens before the second counting period, the colour used for the second counting is used to mark the pod so that it will not be counted as a new ripe pod in the subsequent counting periods. This is illustrated below:

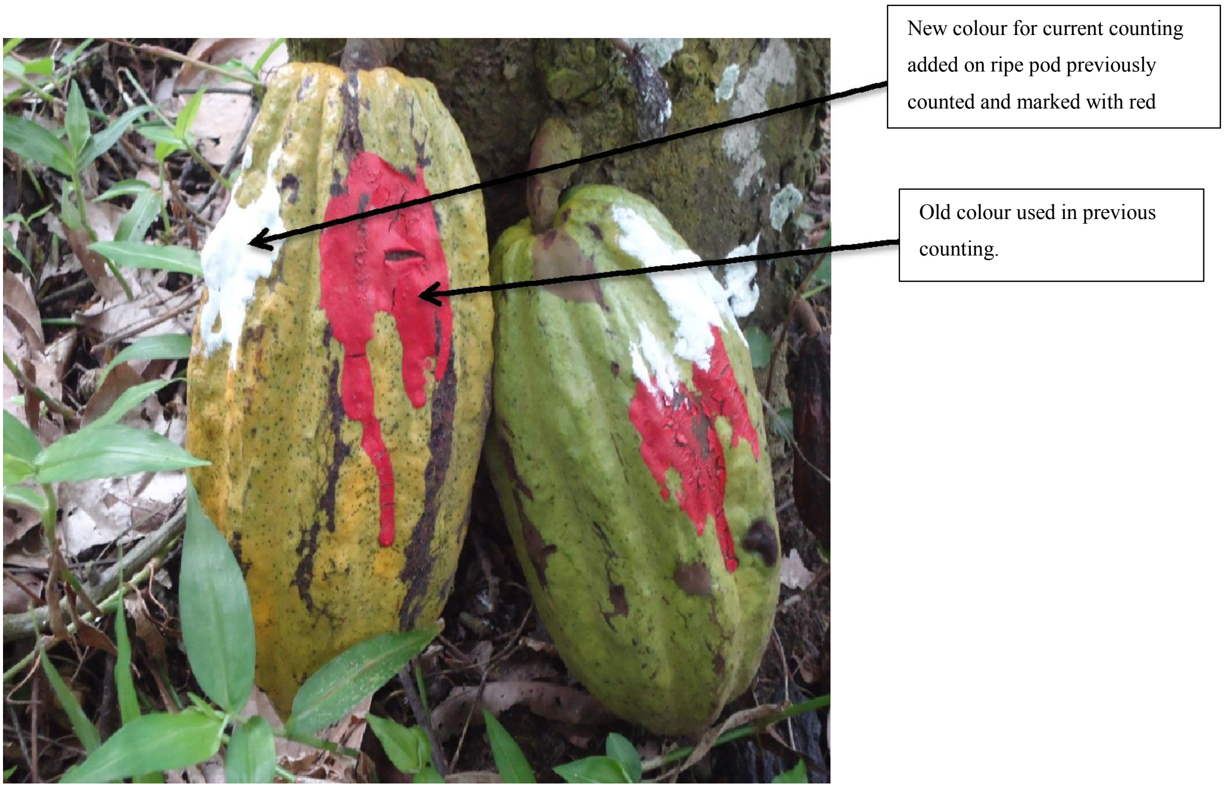

Figure 6: Picture of the method of avoiding double counting ripe pods.

Actual yield (Ya) is defined as the yield achieved by farmers in a given region under dominant management practices (sowing date, cultivar maturity, and plant density) and soil properties. The actual yield here will be gotten from the number of pods that reach maturity and the same formula used in evaluating potential yield is applied here.

3.3 Possible sources of variation in yields.

3.3.1 The age of the farm

The age of the farm is an important characteristic of the farm which could have significant influence on the productivity of the farm. To study the evolution of crops in a milieu in time, a chronosequential study of the milieu is essential. Chronosequences are often used to study the changes in plant communities and study the time-dependent development of a forest, in this case agro-forests. To thus evaluate the evolution of yields of cocoa in the agro-forests in Bokito with time, the study uses farms of different ages (from date of creation to present date). This led to the classification of the study plots in different age groups on the two main types of preceding vegetation (Table 1).

3.3.2 The preceding land occupation or vegetation

This is the former utilisation of the land on which the cocoa agro-forests was created. In this case it is either a forest or savannah preceding vegetation since the study site is in a forest-savannah transition zone. The preceding land occupation can be a serious yield determinant and so the farms where chosen such that all age groups are represented in the two preceding vegetation.

3.3.3 The structure of the cocoa population

It is an important variable which could explain yield differences. This is described by determining the architectural profile of the cocoa population. The architecture of a cocoa tree depends on the type of management treatment the farmer gives the tree. In this study, the architectural profile of the agro-forests in Bokito is described individually from six architectural types following the model proposed by Jagoret in 2011. The architectural profile of a cocoa population is the proportion expressed in % of the different architectural types which characterises it.

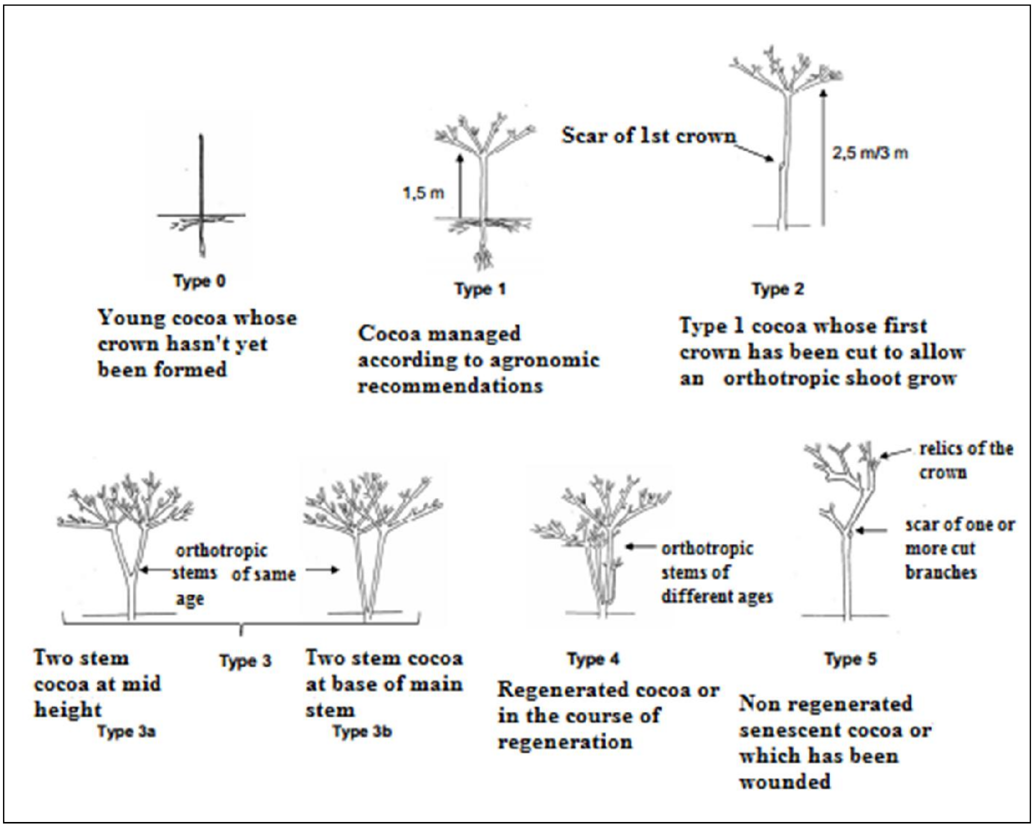

Figure 7: Cocoa architectural types

Source: Jagoret, 2011

Types 0 and 1 correspond to the 1st development stages of cocoa managed with only one stem at the level of the first crown as recommended by agronomic research. Type 2 corresponds to cocoa on which the farmer allows one orthotropic shoot to grow above the first crown increasing the height of the plant and form the second crown. Types 3a and 3b correspond to cocoa which originally starts growing orthotropically but its growth is interrupted by the destruction of the terminal bud. This favours the growth of two lateral buds of the same age at the base (3b) or at mid height (3a) with each growing orthotropically and forming its own crown. Type 4 corresponds to senescent cocoa regenerated by the farmer or in the course of being regenerated and on which the farmer allows the growth of several orthotropic shoots of different ages at the base of the main stem before finally eliminating it. Lastly, type 5 corresponds to non-regenerated senescent cocoa or to cocoa which has been wounded in the past and has lost part of its crown (Jagoret, 2011).

3.3.4. Botanical composition and vegetation structure of the sample

3.3.4.1 The density of cocoa trees/ha

The number of trees in each sample plot is counted and the cocoa density per hectare is extrapolated from the number of individuals counted in each sample plot.

3.3.4.2 Associated trees management and conservation

In the agro-forest systems in Bokito, there are numerous tree species associated with cocoa either introduced into the farm or conserved during the creation of the farm. When land is cleared, indigenous fruit, medicinal, and timber tree species (e.g. groundnut tree (*Ricinodendron heudelotii*), cola (*Cola nitida*), *Voacanga africana*) are deliberately retained both for their economic value and to provide shade for the cocoa plant (Duguma *et al*, 2001). The species richness of each farm is obtained from data collected in 2013. The fruit trees in the study farms are inventoried over all the total area of each cocoa forest. The production/year and the destination of the production of the fruits are evaluated with the help of the farmer and this done with the help of a questionnaire, (annex 5)

The frequency of each fruit species (F, %) is calculated by the following equation:

$F_i = N_i/N$

Where Ni is the number of trees of species i in the entire sample, while N is the total number of trees in the sample. From the frequency of each fruit tree species it would be possible to determine the preference choice of farmers and why the choice. A diversity index called the Shannon-Weaver Index is a commonly used diversity index that takes into accounts both abundance and evenness of species present in the community. It is explained by the formula:

S

$H = -\sum (Pi * \ln Pi)$

i=1 where,

H = the Shannon diversity index,

Pi = fraction of the entire population made up of species i (proportion of a species i (Ni) relative to TOTAL number of species present(N), not encountered),

S = numbers of species encountered.

Here, a high value of H would be a representative of a diverse and equally distributed community and lower values represent less diverse community. A value of 0 would represent a community with just one species.

3.3.4.3 Basal area

There are two types of basal areas and these are the tree basal area (TBA) and the stand basal area (SBA). According to Rondeux (1993), the basal area of a tree is the cross-sectional area of a tree's trunk at breast height (1.3 m). It is the surface occupied by a tree I in a hectare of land. The basal area (TBA) is a simple function of diameter:

$$\mathbf{TBA}=\frac{\pi D i^2}{4}$$

Where TBA=Basal area (m^2 or cm^2/ha) and Π=3.1

D_i=diameter of tree i

The average basal area per cocoa tree is a major determining factor in cocoa yield. This variable is linked to the average number of pods per cocoa tree. The positive relationship between the average number of trunks per cocoa tree and the average basal area per tree, due to the coppicing of senescent cocoa trees, appears to have an important role in the long-term maintenance of cocoa yields (CIRAD, 2009). A related vegetation characteristic is stand basal area. It is the sum of all individual tree basal areas of all the trees in the sample. It is usually expressed on a per area basis, such as m^2/ha. It is given by;

$$\mathbf{SBA} = \sum_{i=1}^{n} \frac{\pi D i^2}{4} \times \frac{d}{n}$$

With: SBA= basal area of a stand of trees, Di= diameter of tree i, d= population density/ha, n= number of individuals in sample plot.

The TBA and hence the SBA will help in the estimation of the surface area occupied by the cocoa stands with respect to the trees associated with cocoa. This will give an idea on the amount of shade present in the farm. The higher the SBA of associated species than that of the cocoa stand, the more the shade which would reduce the amount of sunlight entering the farm and as such cocoa trees will grow very tall due to completion for light where as a lower

SBA for associated trees will imply more sunlight into the farm thus the cocoa plants will be shorter. This gives an indication of the vigour of cocoa plants in each case and there is a strong relationship between productivity and vigour and this has been brought forth by many authors (Glendinning, 1960; 1966; Lachenaud and Mossu, 1985).

3.3.4.4 Cocoa biomass and carbon stocks

Terrestrial carbon (C) stocks is the term used for the C stored in terrestrial ecosystems, as living or dead plant biomass (aboveground and belowground) and in the soil, along with usually negligible quantities as animal biomass. Aboveground plant biomass comprises all woody stems, branches and leaves of living trees, creepers, climbers and epiphytes as well as understory plants and herbaceous growth while the belowground biomass comprises living and dead roots, soil fauna and the microbial community.

In calculating the above grown biomass (AGB) of the cocoa population in the cocoa agro-forests, the model proposed by Chave *et al.*, (2006) and already used by Saj *et al.*, (2013) in Bokito's AFS is used in this study. According to this model:

AGB_i (kg) $=\exp[-2.187 + 0.916 \ln(W_i \times (DBH_i^2) \times H_i)]$

$=0.112 \times (W_i \times (DBH_i^2) \times H_i)^{0.916}$

Where in this equation AGB_i represents aboveground biomass of an individual tree, Hi individual tree height and W_i specific density of the tree. AGB is expressed in kilogram (kg), DBH in centimetre (cm), H in meter (m) and W in g/cm^3dry weight. Chave *et al*., (2005) model is based on trees harvested from dry and moist tropical forest sites around the world (rainfall less than 1500 mm) and requires data on DBH, height (H) and wood specific density (W) for each tree. All these parameters where measured the specific wood density for cocoa of 0.42 g cm^3 was used so as to be coherent with the model used (Chave *et al*., 2006).

Below ground or tree root biomass (BGB).

In calculating BGB, the method proposed by COMIFAC in 2008 is used:

BGB (t/ha) =AGB x (R/S)

Where AGB is above ground biomass and R/S is the root/stem ratio.

The R/S ratio used here is 0.235 as recommended by Monkany *et al.*, (2006).

Evaluation of carbon stocks

This is obtained by multiplying the sum of the above ground and below grown biomass by the CF (carbon fraction), and according to the GIEC (2005) this CF is 0, 47 which corresponds to the mean of the conventionally used value (Hairiah *et a*l., 2011).

Carbon stocks= CF x (AGB + BGB)

3.3.4.5 Pest and disease pressure

The main pests are insects of the miridae family. The hazards they cause on cocoa is evaluated following a notation scale from 0 to 3 with 0 corresponding to no destruction and 3 corresponding to maximum destruction (Brun *et al*., 1997 ; Sounigo *et al*., 2003). Three different types of destructions are identified:

- presence of dry leaves which correspond to recent mired attacks (a few weeks);
- the presence of nude branches which correspond to old mired attacks about a few months and this is often accompanied by cryptogamic infections;
- the presence of cankers, this shows the cicatrizing response of the plant to mirid attacks and it accumulates on the stem and branches throughout its evolution (Annex 3).

All plots where evaluated and noted for each type of the three destructions caused by mirids and the notation for each plot corresponds to the mean of the four notations attributed (0, 1, 2, 3) (Jagoret, 2011).

3.4 Statistical analyses

Data were collected between April 2014 and November 2014. Potential yield is analysed by two-way ANCOVA (age and preceding culture) in a factorial model including all possible interactions to test the results as well as associating companion trees density and basal area of big trees (DBH> 30 cm) as covariates. Other variables were analysed by two-way ANOVA (age and preceding culture) in a factorial model including all possible interactions to test the results. Where necessary, log transformations are carried out for variance homogenisation. When significant differences are observed, the Tukey's test at 95% was used to compare between treatment means.

Further, the relationship between potential yield, companion trees, basal area and mean height is investigated using an overlay in principal component analysis (PCA) graph with preceding culture and age class as supplementary variables to see the relative position these factors have in the PCA.

Data analysis is done with the help of two software's SPSS 21.0 (IBM) and XLSTAT version 2014 5.02 (Addinsoft).

Chapter 4: RESULTS AND DISCUSSIONS

4.1 Yield evaluations and variables

The average number of pods per tree is 17.3 and the average weight of pods is 497.4 g (0.497 kg). But it is worth noting that on an individual level you can have > 5 pods/tree and up to 100 pods and more/tree showing a large variation. The number of beans seeds per pod is 39.46 while the average weight of normal beans seeds per pod is 118.2 g (0.118 kg). The potential yield on average for all sampled cocoa plots in Bokito is 819.2 kg/ha. With respect to the different potential yield classes, there is a large difference between the class with the highest number of individuals (>1000 kg/ha) and that with the lowest number of individuals (<200 kg/ha). In most of the farms the yields are situated around 1000 kg/ha.

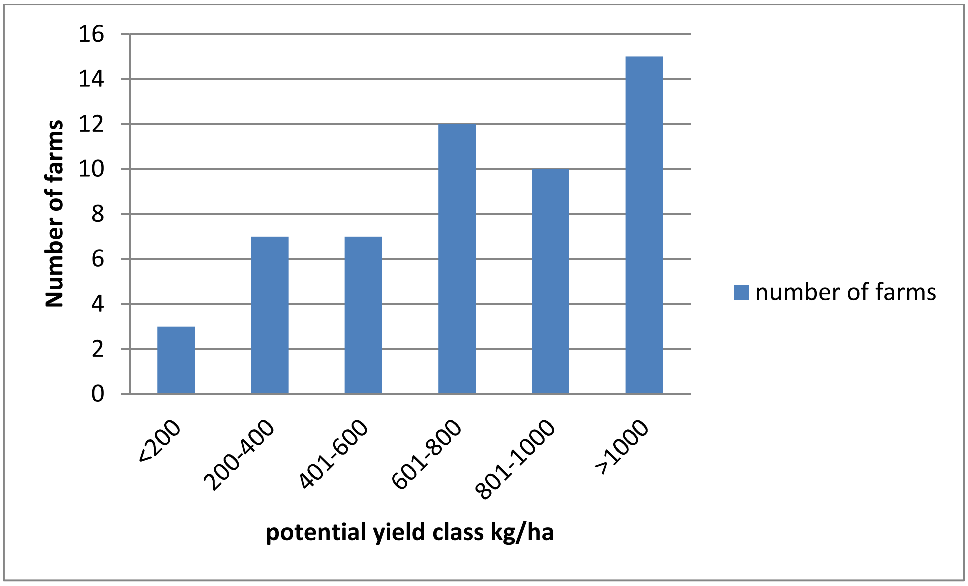

Figure 8: Histogram showing the number of farms per yield class.

The potential yield in Bokito is highest in the age group **> 60 (932.4 kg/ha)** and lowest in age group ≤ 10 (662.2 kg/ha) but the yields can be as high as 1881.1 kg/ha in some farms and as low as 42.9 kg/ha showing that there are large differences when we consider individual farms. There is no significant difference between potential yields in the different age groups (F= 0.723, P= 0.581) as well as with the two preceding vegetation's (F= 0.967, P= 0.331) tested when a two way ANOVA is applied to the data. When an ANCOVA is applied, there is a significant difference of potential yield with respect to the age categories (F= 2.681, P= .049) but non with respect to the preceding culture (F= 0.442, P=0.511). ANCOVA is used so as to get rid of the effects of associated trees because the density of associated trees and the basal area of big trees affect the potential yield. There is thus a significant difference between age group ≤ 10 and all the other group ages and this holds perfectly with the findings of Jagoret in 2011. Yields thus increase significantly with age. On average irrespective of age, potential yields where higher on plots created on savannah (866.9 kg/ha) than those created on forest preceding vegetation (786.6 kg/ha) **but these yields where not significantly different.**

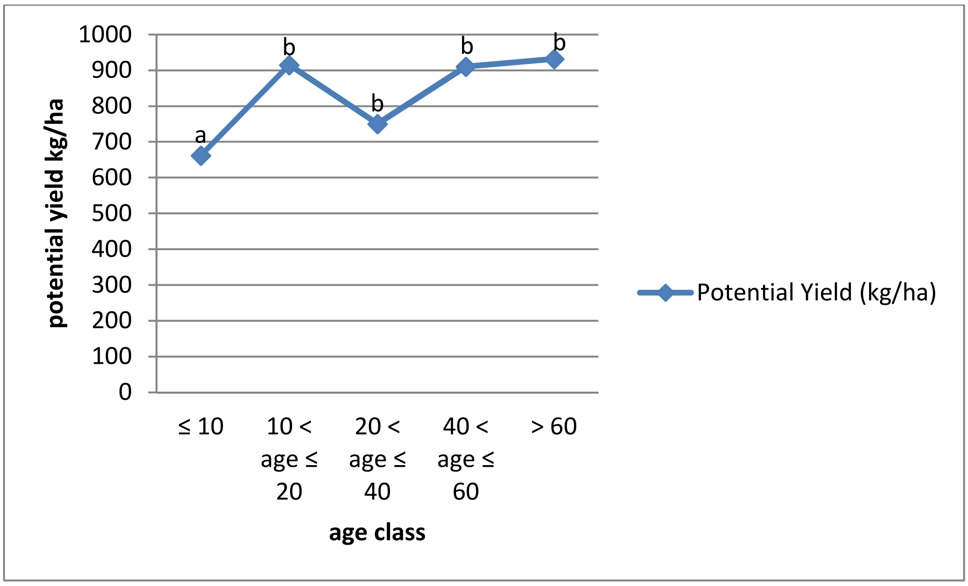

Figure 9: Plot showing the evolution of potential yields with age.

The average number of pods and potential yield obtained is higher than those obtained by Jagoret in 2011. This difference in the results can be explained by the fact that there is an increase in the use of improved genetic material in Bokito cocoa agro-forests as such yields and number of pods per tree is also increasing thus higher than what he obtained. This is supported by the large difference that exist between the highest number of pods on a tree and the lowest suggesting that the higher number of pods corresponds to an improved genetic material and the lower number of pods to the local genetic material. Another plausible reason for the higher potential yield observed is the fact that this study used twice as many fields as Jagoret in 2011. The large difference of yields observed at an individual farm level can be attributed amongst other factors to the management strategies and treatments each farmer applies to his farm.

4.1.1 Actual yield

The proportion of potential yield in Bokito that reaches maturity is 37.4 kg/ha and it represents only 22.5 % of the potential yield. Diseases are responsible for 17 % losses (rotten) while 2.02 % is lost to rodents (eaten by rodents). The values obtained for the actual yields are much lower than what it is in reality. This is because the farmers harvest ripe pods and do sanitation harvest successively. So before each period of data collection, these operations have been done as such made faulty the results observed. **Also, the time allocated for this research work ended before most of the pods got ripe so the real quantity which the farmer gets could not be evaluated.** The only useful information which can be gotten from this is that after mirids (highest damage causer on cocoa in Bokito as compared to other productions zones in central Cameroon (Jagoret (2011)), the next factor which reduces the proportion of the potential yield that reaches the farmer is disease incidence followed by animal damage (rodents especially).

4.2 Effect of the structure of the cocoa population

4.2.1 Architectural profile

The architectural types (Figure 8) 5, 2 and 4 are the most represented in the cocoa population. On average, type 5 represents 37.4 %, type 2 represents 19.8 % and type 4 represents 18.1 % of the cocoa population while types 1, 3a and 3b are the least abundant representing respectively 8.7 %, 12.6 % and 3.4 % of the cocoa population. One notices an increase in abundance of type 5 as we increase in age of the farm with a corresponding decrease in type 1. Also there is an increase in the proportion of type 4 with an increase in age of the farms.

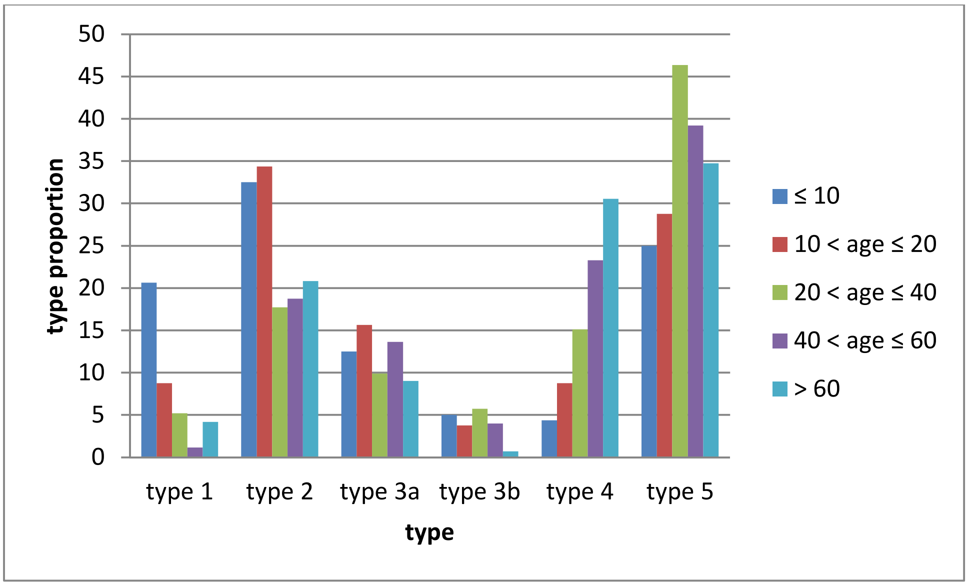

Figure 10: Histogram showing the evolution of architectural types with age.

The architectural profile trend corresponds perfectly to that observed by Jagoret 2011 in Bokito. The increase in type 4 with age of the farm is proof of the activity of regeneration by farmers in Bokito. As farms age, plants may die, or produce very little or are attained by a disease or a fatal accident. This causes the farmer to replace them and this explains why there are type 1 trees in all the age groups. The yield and type four trees increase with age. This shows or proves that there is an effect of regeneration activities on yield. This should be investigated in further research to ascertain the effect of regeneration on the yields of cocoa in agro-forests.

4.3 Botanical composition and vegetation structure

4.3.1 Density

The average density of cocoa population in Bokito is 1222 plants per hectare. According to Jagoret (2011), the density recommended by agronomic research is between 1300 and 1600 plants per hectare. Of all the plots sampled, only 6 have densities falling within the recommended planting density, 8 have densities higher than this and 40 have densities lower than this recommended range. The cocoa densities proved to be significantly different with respect to age (F=5.905, P=0.001). But on the contrary no significant difference was observed between cocoa densities with respect to the preceding **vegetation.** The age class 10 < age ≤ 20 shows the highest density (1809 ind/ha) while the age class >60 shows the lowest density (901 ind/ha). This reveals a gradual decrease in cocoa density per hectare with time.

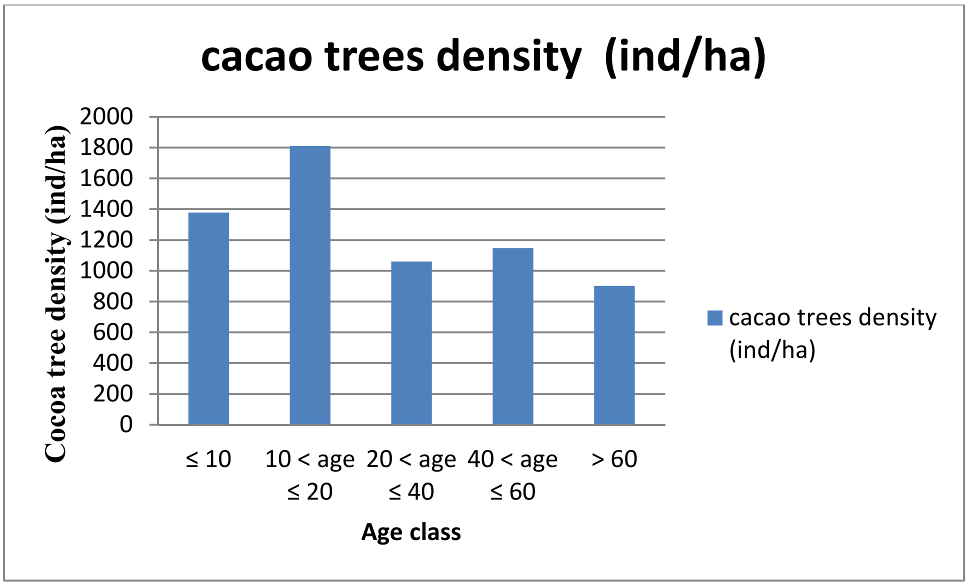

Figure 11: Histogram of cocoa tree density with respect to age.

Table 2: Average cocoa density of farms with respect to the age of the farms.

Age	Mean density(ind/ha)
≤ 10	1377.5 ± 425 (abc)
10 < age ≤ 20	1670 ± 525.8 (ab)
20 < age ≤ 40	1060 ± 262.35 (ac)
40 < age ≤ 60	1147 ± 287.1 (ac)
> 60	901.2 ± 191.1 (ac)

On the columns, values followed by the same letter are not significantly different (Tukey's test at p=0.05)

The densities of cocoa observed are below those recommended by agronomic research. The density of cocoa trees decreases with age in Bokito but yields tend to show slight increase The lower density at age class ≤10 than at age class 10 < age ≤ 20 may be explained by the fact that since the farms are not created following a regular pattern, the young plants may die or are destroyed by animals and it is in due time that they are replaced and as such the farm gains its stable density only after about ten years of age and with time due to ageing and other factors like disease, the density starts to drop due to death of plants. This also shows a low level of follow up of farms by farmers who do not regularly replace dead plants thus leading to a progressive decline in density.

Advice on cocoa density is generally aimed at controlling weed. In farmers' fields reduction of density does not necessarily slow cocoa production. A study by Sonwa in 2004 reveals that where pesticides are not applied, high density of cocoa do not provide more cocoa beans production. And this corresponds to what was observed from survey in Bokito. Farms with very low density (600-900 ind/ha) most at time farms of age >40 years had higher yields than high densities farms <20 years. Upon further survey it was discovered that the owners of these low density farms took greater care in terms of clearing their farms and suffered less from diseases (for they believe that since their farms are old they would not produce if they are not properly taken care of) but owners of high density farms had little weeds but they confirmed that if they did not treat their farms against diseases, they had very little yields. Because of this observation an age density interaction effect on yield was checked but no interaction was found. But it is clear that density has an effect on yield which could not be accurately proven by this study. This should be investigated in detail in further research studies.

4.3.2 Basal area

The average basal area observed per tree is 61.3 cm^2 with the highest being 388.6 cm^2 and the lowest being 3.1 cm^2. This shows great variation in tree basal area. The stand basal area observed which gives us an idea on the coverage of the farm with respect to other associate trees is on average 25.5 m^2/ha with the highest value observed in age group $40 < age \leq 60$ (33.1 m^2ha) and the lowest in age group ≤ 10 (13.5 m^2/ha). It is remarked that there is an increase in the stand basal area with increase in age of the farm. There are significant differences between the basal areas with respect to the different age groups (F=7.169, P=0.000).

Table 3: Average basal area with respect to age of cocoa farms

Age	**Basal area (m^2/ha)**
≤ 10	13.5 ± 9.2 (ac)
10 < age ≤ 20	24.6 ± 8.6 (ac)
20 < age ≤ 40	23.4 ± 8.1 (ac)
40 < age ≤ 60	33.1 ± 10.6 (bc)
> 60	31.5 ± 10.3 (bc)

On the columns, values followed by the same letter are not significantly different (Tukey's test at p=0.05)

This explains the increase in yield with age since the surface area occupied by cocoa plants increases with age. This is linked to the fact that the diameter of the plants increase with age and that the practices of regeneration practiced leads to increase in type four cocoa trees with many stems and thus more diameter and coverage. The higher number of stems will bear a higher number of fruits than the plant could bear before. It thus confirms the affirmations of CIRAD, 2009 that the positive relationship between the average number of trunks per cocoa tree and the average basal area per tree, due to the coppicing of senescent cocoa trees, appears to have an important role in the long-term maintenance of cocoa yields.

4.3.3 Cocoa biomass and carbon stocks

In bokito the average cocoa dry biomass is 15902 kg/ha with the highest biomass being recorded in farms of age >60 years (23567 kg/ha) and the lowest in younger farms of age ≤ 10 years (6828. kg/ha).

The average carbon stocks in Bokito is 7.5 t/ha with the highest from age class >60 years (11.1 t/ha) and the lowest from age class ≤ 10 (3.2 t/ha). The carbon stocks vary in the same way as the biomass as shown on figure 13. There is a steady increase in biomass and carbon stocks with increase in age. There is no significant difference between the forest and savannah preceding culture but on the contrary, there are significant differences between the age groups (F=13.841, P=0.000) or classes as shown on the table below:

Table 4: Average cocoa dry biomass and carbon stocks with respect to age of cocoa farms.

Biomass	
Age class	Mean (t/ha)
≤ 10	6.8 ± 3.2 (a)
10 < age ≤ 20	11.7 ± 2.9 (a)
20 < age ≤ 40	15.4 ± 6.4 (b)
40 < age ≤ 60	21.1 ± 7.95 (bc)
> 60	23.6 ± 6.0 (c)
Carbon stocks	
Age class	Mean (t/ha)
≤ 10	3.2± 1.5 (a)
10 < age ≤ 20	5.4 ± 1.35 (ac)
20 < age ≤ 40	7.2 ± 2.9 (bc)
40 < age ≤ 60	9.9 ± 3.7 (bc)
> 60	11.1 ± 10.3 (b)

On the columns, values followed by the same letter are not significantly different (Tukey’s test at p=0.05)

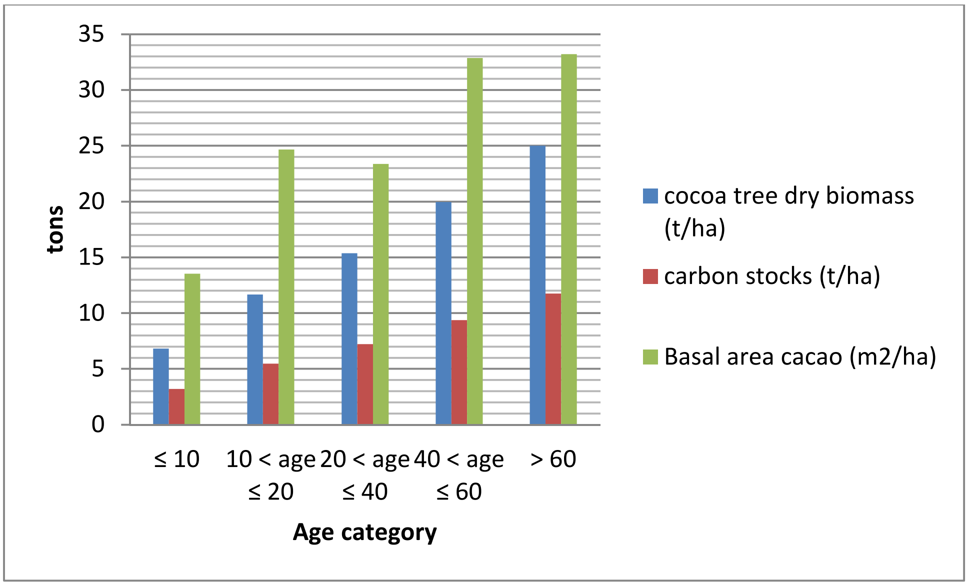

Figure 12: Histogram of tree dry biomass, carbon stocks and basal area with age.

Pertaining to biomass and carbon stocks, the biomass of a plant can be used to estimate the amount of carbon stocked by the plant. The steady increase in biomass observed can be explained by the fact that with time the plant is increasing in height and size of the trunk. Saj et al., (2013) found on average in centre Cameroon total C content of live trees close to 70 t ha-1 but that it mostly relied on associated trees, with cocoa trees contribution being 2–12 % of live trees total C. From this one can conclude that cocoa trees do not store much carbon. This corresponds with the results obtained by this study for the observed cocoa carbon stock (7.5 t/ha) falls within this range of 2-12 %. There is a clear pattern between cocoa production and carbon stocks for potential yield shows significant increase with increase in carbon stock proving thus the strong uphill relation observed at correlation tests. But, emphasis on using cocoa agro-forest for climate change mitigation should be based on associated tree which store the greater part of carbon and not on cocoa.

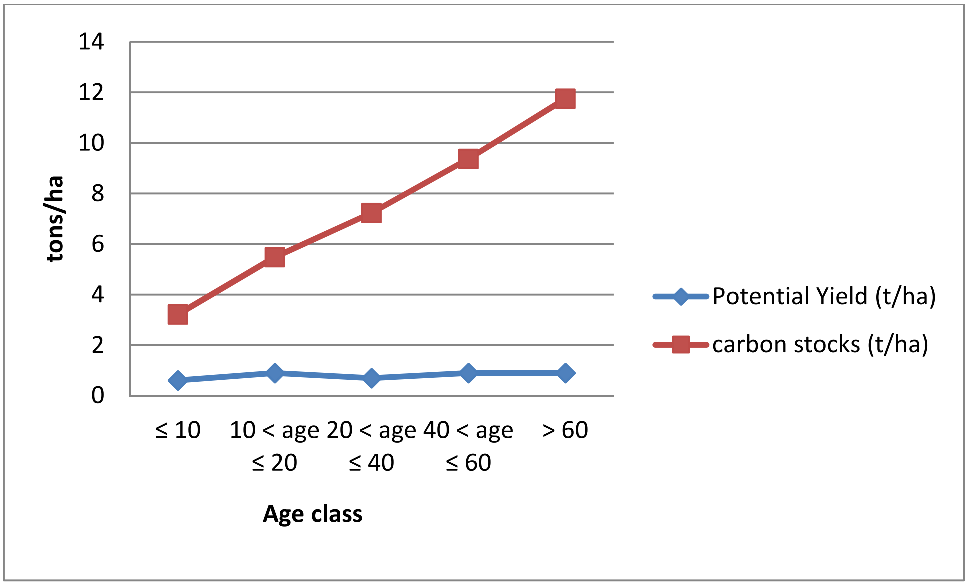

Figure 13: Evolution of cocoa carbon stocks and potential yield with age.

4.3.4 Associated trees management and conservation

From the 54 sample plots, a survey of 49 plots was done to evaluate the number of fruit tree species in each farm and determine why the farmers choose to introduce or conserve those species in their farm. This is because these fruit trees have different destinations and uses attributed to them by the farmer. It is observed that there are 14 different fruit species with each farm having at least one of these and these fruits trees include: *Citrus sinensis* (orange), *Dacryodes edulis* (plums), *Citrus recticulata* (mandarin), *Elaseis guineensis* (palm tree), *Persia Americana* (Avocado), *Cola nitida* (cola), *Mangifera indica* (mango), *Citrus paradisi* (grape fruit), *Anacardium occidentale* (cashew nut), *Citrus aurantifolia* (lime), *Carica papaya* (pawpaw), *Psidium guajava* (Guava), *Cocus nucifera* (coconut), *Citrus limon* (lemon). From the 49 farmers, it was observed that the farmers introduced or maintained oranges, mandarins, grapes, plums, cashew nuts, lime and lemon for sales. 99% of them preferred citrus fruits especially oranges, grapes and mandarins because their fruits have a high price in the market and is an extra source of revenue while lime and lemon where sold but also for medicinal purposes. Only very interesting avocado species fruits are destined for the market. The remaining fruits are exclusively for consumption only in very rare cases taken to the market. It is worth noting that all these fruits are not just a source of revenue but also a source of food for the households. In Bokito, mature trees can produce in a year 120kg, 120kg, 90kg, 300kg, 185, and 175kg for *Dacryodes edulis, Citrus sinensis, Citrus recticulata, Mangifera indica, Citrus paradisi, and Persia Americana* respectively.

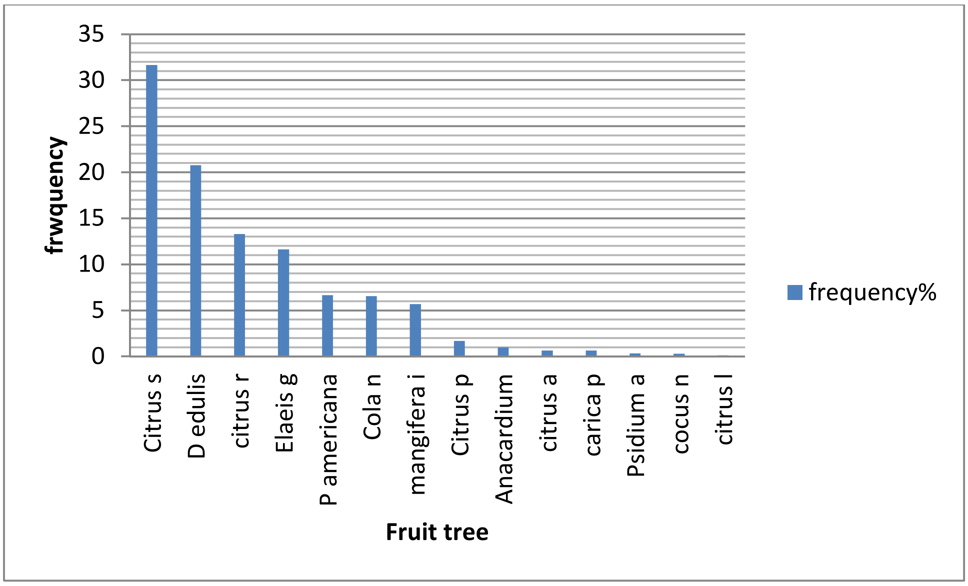

Figure 14: Histogram of the frequency of fruit trees in Bokito.

The Shannon weaver index for cocoa agro-forests in Bokito is on average 0.85 for a species richness of 14.58. There is no significant difference of Shannon index with respect to age (F=0.64, P=0.992) but it is significantly higher in forest than on savannah previous vegetation (F=4.790, P=0.304). There are significant differences between age groups with respect to species richness (F=2.199, P=0.040), and between the two preceding vegetation (F=4.183, 0.47). Species richness decreases with age of the cocoa agro-forest.

Table 5: Species richness with respect to age

Species richness	mean
≤ 10	11.3 ± 2.2 (a)
10 < age ≤ 20	8.9 ± 2.7(ab)
20 < age ≤ 40	8.6 ± 3.1(ab)
40 < age ≤ 60	7.7 ± 2.1(ab)
> 60	9.5 ± 3.2(b)

On the columns, values followed by the same letter are not significantly different (Tukey's test at p=0.05).

The main functions played by the plant are important factors taken into consideration when deciding to introduce or maintain the plant in cocoa agro-forests. The utility of species, their phenological pattern and their growth rate are the main criteria given by farmers when selecting plants for cocoa agro-forests (Oduro-Ameyow *et al*. 2003). Fruit trees are generally prosperous where accessibility to the urban centers (where markets exist) is good. This for example, is the case around the Lekie and Mbam divisions of Cameroon (Gockowski *et al*., 2004). But those near the market (i.e. around Yaoundé) have the following: 6 consumables, 1 medicinal, 4 timber and 4 other plant species. A survey found that farmers of southern Cameroon usually plant on average 7 plant species (4 fruits and 3 non-fruits) to diversify the cocoa plantations (Sonwa 2004). This clearly shows that to make the system more market oriented, efforts need to focus mainly on edible, medicinal and timber plants. From the survey, the number of fruit trees per farm in Bokito is 14 which is higher than that reported by Sonwa (2004) this clearly proves the fact that farmers in Bokito opt for preserving fruit trees in their farms for extra source of revenue and just as mentioned earlier 99% of the farmers did this because they sold the fruits in the market. This confirms Gockowski *et al*., (2004) statement on the 6 consumable fruit trees for those near the market and Bokito is near urban centre like Bafia and Cameroons capital city Yaoundé.

As agroforestry is becoming a more important science and seems a tool for development in central and West Africa, scientists such as Leakey (1998) advice the use of species such as *Baillonella toxisperma, Canarium schweinfurthii, Cola spp, Coula edulis, Dacryodes edulis, Irvingia gabonensis* for domestication programs inside multistrata agroforestry systems of the Humid Forest Zone of West and Central Africa. This recommendation is not far from the farmer's priority which is using trees which can procure food and income. As such, emphasis when giving such recommendations should be place on edible fruit trees.

4.3.5 Pest and disease pressure

The average notation attributed to plots for evaluating pest and disease pressure with respect to mirid attacks is 0.69 as concerns the presence of old cankers, 0.66 as concerns the presence of dry leaves, and 0.73 as concerns the presence of nude branches on a scale of 0-3. There are no significant differences observed for the three types of notations with respect to the preceding vegetation and the age groups as concerns the presence of old cankers($F=1.338$, $P=0.271$) and dry leaves ($F=1.318$, $P=0.278$) . But between age group > 60 and the other age groups with respect to nude branches ($F=3.149$, $P=0.23$), there is a significant difference observed. It is observed that the destruction caused by mirids increases with the age of the farm. This is because the destructions caused accumulate on the stem and branches of the plant with time especially with respect to the presence of old cankers.

Table 6: Average notation of destructions caused by Mirids

Age class	Presence of old cankers	Presence of dry leaves	Presence of nude branches
≤ 10	0.34 ± 0.28(a)	0.46 ± 0.32(a)	0.36 ± 0.37(ac)
10 < age ≤20	0.83± 0.37(a)	0.64 ± 0.22(a)	0.76 ± 0.28(ac)
20 < age ≤ 40	0.70 ± 0.53(a)	0.71 ± 0.39(a)	0.78 ± 0.43(bc)
40 < age ≤ 60	0.69 ± 0.41(a)	0.68 ± 0.29(a)	0.79 ± 0.26(bc)
> 60	1.87 ± 0.36(a)	0.76 ± 0.19(a)	0.93 ± 0.23(d)

On the columns, values followed by the same letter are not significantly different (Tukey's test at p=0.05)

The most frequent destruction observed was the presence of nude branches. As of cankers, they appear due to the cicatrising effect of the tree when pierced by the mirids or due to the mirid laying eggs in the bark of the tree. This spot bearing the canker will never be able to bear fruit thus impact the production potential of the tree thus yields. This proves that if mirids are left unattended, yielding potential of cocoa trees can be greatly reduced.

4.4 Relationship between cocoa yields and yield factors

Correlations between the variables are examined with Pearson at 0.05 (Annex 4) and for a better visualisation of the relationship that exists between the potential yield and all yield factors investigated, a principal component analysis (PCA) graph is used to present the results.

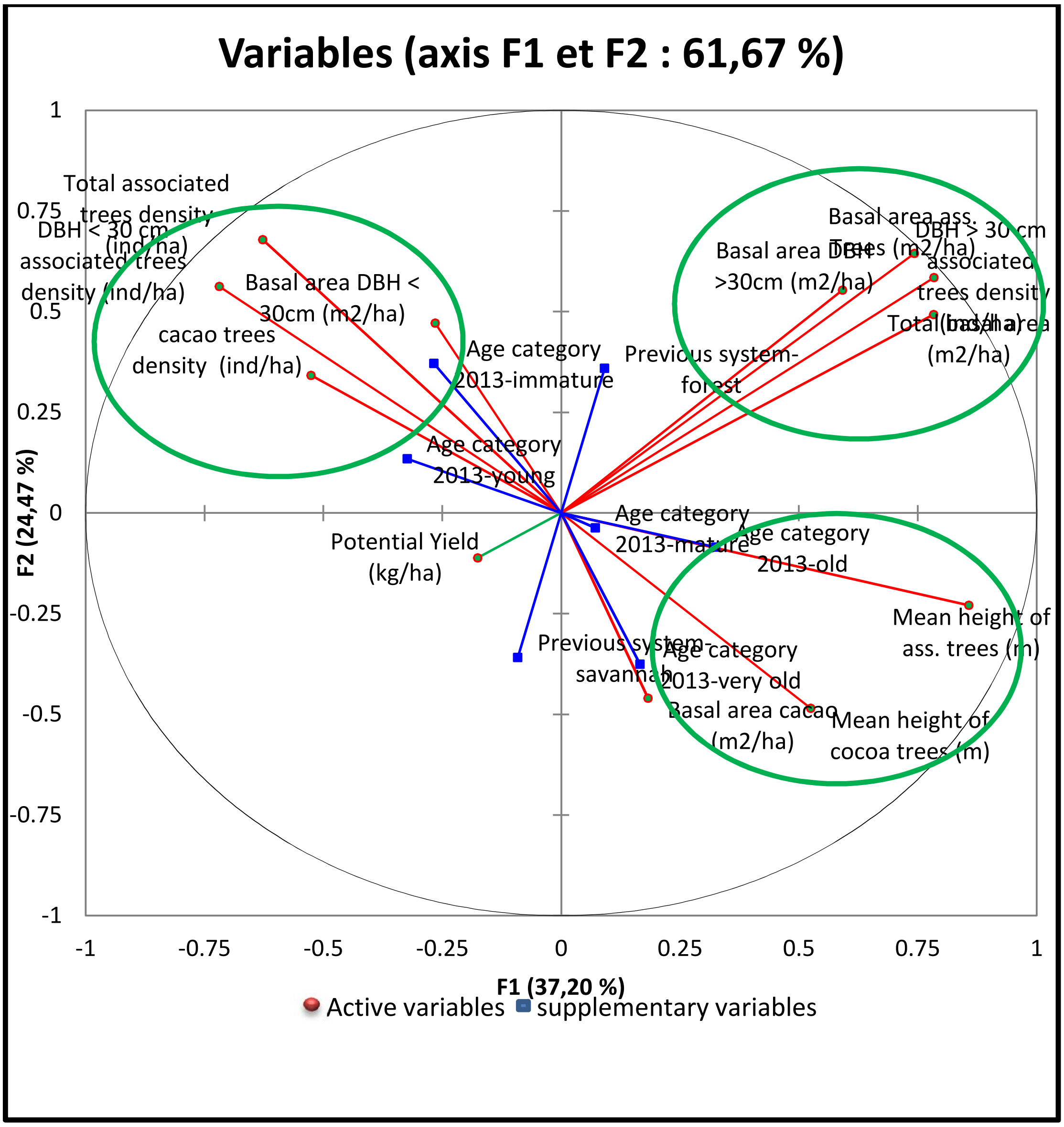

Figure 15: Principal component analysis graph.

On the PCA, the F1 and F2 axis represent 61.67% of the information. The F1 axis opposes variables of associated trees (basal area DBH>30cm, density, mean height, total basal area) and some cocoa population structure variables (basal area, mean height) to cocoa tree density and associated tree variables (density and basal area DBH<30). The supplementary variables show that preceding forest systems are better associated with big tree variables and lower potential yield while preceding savannah systems are better associated with mean heights of associated and cocoa trees as well as cocoa tree basal area and higher yields.

From the correlation table (annex 4) it is observed that:

- potential yield increases significantly with cocoa tree basal area.

- there is a weak linear relationship between potential yield and the mean height of cocoa trees.
- there is a strong positive relationship between potential yield and cocoa carbon stocks
- there is a strong positive relationship between basal area of cocoa and mean height of cocoa trees and a very strong relationship with cocoa carbon stocks.
- there is a strong positive relationship between mean height of cocoa trees and mean height of associated trees and a very strong relationship with cocoa carbon stocks but a negative linear relationship with total associated tree density.
- there is a weak linear relationship between total basal area and mean height of cocoa trees.
- a strong negative linear relationship exists between mean height of cocoa trees and trees of diameter at breast height <30cm.
- there is a moderate linear relationship between associated trees of diameter at breast height <30cm and total associated tree density.
- there is a weak positive linear relationship between cocoa carbon stocks and a moderate linear relationship with mean height of associated trees.

Chapter 5: CONCLUSIONS AND RECOMMENDATIONS.

5.1 Conclusions

The methodology adopted and used in this study has already been used in several research findings in cocoa agro-forests and it has revealed new and confirmed existing information for better understanding complex cocoa agro-forest systems.

The evaluation of yields has permitted the situation of the level of the yields in Bokito cocoa agro-forests (819.2 kg/ha).

Analysis of the components of the cocoa agro-forests in Bokito have confirmed that yields of cocoa in these systems mostly relies on the structure of the cocoa population (here the stature, biomass of the plant is looked at). The basal area cacao (m^2/ha) has been shown to be one of the most important factors on which cocoa yields in this system depend on. The relationship between mean height of cocoa trees (m), cocoa carbon stock (t/ha) and potential yield has been demonstrated by the results of this work. So in creating cocoa farms, it is recommended to use all management strategies that will let the plant be very vigorous for example allowing sufficient shade in the early years to make the plant grow tall thus more biomass and basal area but this shade should be reduced with age of the farm to a considerable level. Also revealed is the diverse management strategies adopted by farmers in managing their family agro-forests which is multi crop farms. The potential yield increases significantly with age but is not different whether it is on savannah or forest. But at an individual level there are large variations in potential yield depending on the care each farmer gives his farm.

Farmers prefer citrus fruit trees to other fruit trees due to the good price of their fruits on the local markets. From this study practical recommendation as to cocoa density and associated trees can be deduced for optimisation of cocoa yields and improvement of farmers living conditions, conservation of biodiversity and improvement on the incomes thus standards of living of the smallholder cocoa farmer.

In a nutshell, cocoa yields are mostly related positively to cocoa basal area, cocoa carbon stocks and the mean height of cocoa trees but not forgetting that these variables also depend on the associated trees present in the farms. This suggests lines of cocoa yield maximization in cocoa agro-forests.

5.2 Recommendations

In view of further optimisation of cocoa agroforestry systems, a series of recommendations are addressed to the different parties involved in the food sector and these include research institutions (for further research), the state (for better policy development and implementation) and the local farmers for better farm management at the production zones.

5.2.1 Research institutions

Research institutions are advised to:

- investigate more on the development of cocoa varieties which are more productive and well adapted to the context of a complex cocoa agro-forest.
- investigate in detail on the effect of the interaction between age and density on yields.
- orient research towards higher biodiversity of fruit trees adapted to competition that exists in complex cocoa agro-forest systems so as to increase the amount of non-cocoa useful products to improve on the revenue of local farmers hence their standards of living.
- Investigate the effect of each of the main fruit trees in the agroforestry systems in Bokito on the physico-chemical characteristics of the soil, shade provision and consequently on cocoa yields.

5.2.2 The state and non-governmental organisations

The state is advice to create a data base for the collection of all research results for regional analysis in order to develop policies based on the realities exposed by research findings. Added to this the state is advised to increase support towards the local farmers and encourage young people to get into the farming activity. Last but not the least she should finance research geared towards the optimisation of yields in all traditional farming systems since they prove to be sustainable and environmentally friendly in the long run.

5.2.3 The local farmers.

The large disparity observed at an individual level with respect to yields in this study is explained by the treatment each farmer gives his farm. So from this the farmers are advised to:

- increase the number of times their farms are cleared in a year.
- respect their treatment calendars so as to reduce the incidence of pest and diseases.
- make themselves familiar with agricultural vulgarisation agents for the latest useful information in improving of their farms.

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ANNEX

Field n°		Farmers name		GPS Coordinates		N :	4.58346	E :	11.1567		N :		E :	
1		Biedi Barthelemy		of angles		N :		E :			N :		E :	
							Square size according to GPS (m²)							

1 cell = number of pods counted on one cocoa tree

Passage 1 / date : 18/04/2014 / peinture :Blue

cocoa 1	0	cocoa 9	0
cocoa 2	0	cocoa 10	0
cocoa 3	0	cocoa 11	0
cocoa 4	0	cocoa 12	0
cocoa 5	0	cocoa 13	0
cocoa 6	0	cocoa 14	0
cocoa 7	0	cocoa 15	0
cocoa 8	0	cocoa 16	0
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		
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0	0		
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0	0		
0	0		
0	0		
0	0		
0	0		
0			
0			
0			
0			
0			
total 1 =	0		

1 cell = number of pods counted on one cocoa tree

Passage 2 / date : 23/06/2014 / peinture :Red

cocoa 1	0	cocoa 9	0
cocoa 2	0	cocoa 10	0
cocoa 3	0	cocoa 11	0
cocoa 4	0	cocoa 12	0
cocoa 5	0	cocoa 13	5
cocoa 6	0	cocoa 14	1
cocoa 7	5	cocoa 15	0
cocoa 8	0	cocoa 16	0
0	2		
0	0		
0	0		
0	0		
7	0		
0	0		
2	0		
0	0		
0	0		
2	0		
5	0		
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		
3	0		
0	0		
0	0		
0	0		
0	0		
0	0		
0			
0			
0			
0			
0			
total 2 =	32		

1 cell = number of pods counted on one cocoa tree

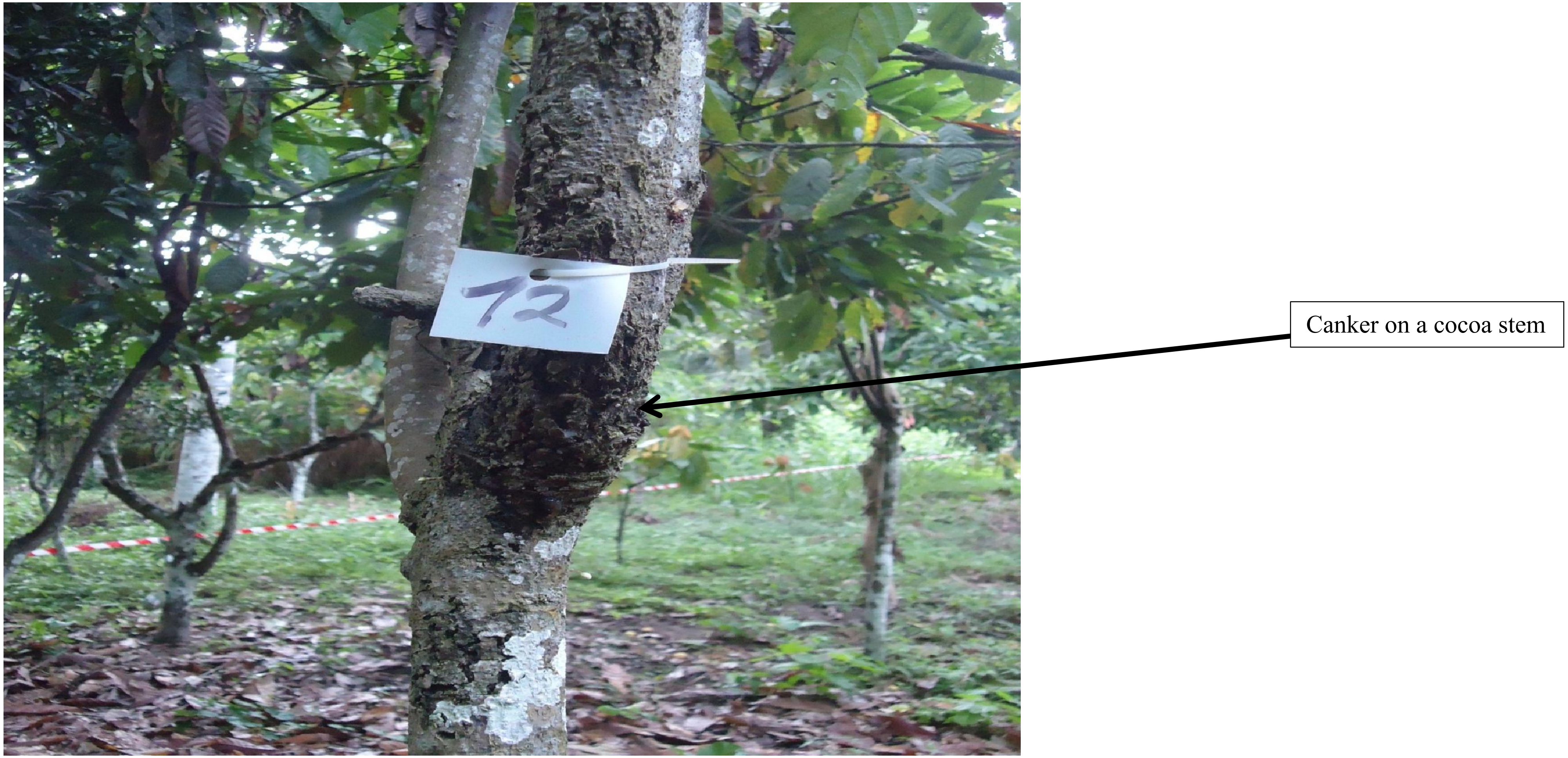
Passage 3 / date :01/09/2014 / peinture : white

cocoa 1	0	cocoa 9	1
cocoa 2	0	cocoa 10	0
cocoa 3	0	cocoa 11	0
cocoa 4	1	cocoa 12	0
cocoa 5	0	cocoa 13	23
cocoa 6	0	cocoa 14	0
cocoa 7	11	cocoa 15	0
cocoa 8	9	cocoa 16	0
2	0		
0	55		
0	0		
0	2		
0	56		
0	0		
0	0		
2	0		
21	0		
82	0		
0	0		
0	3		
8	0		
0	0		
0	0		
0	0		
0	0		
0	0		
2	6		
0	0		
0	0		
0	0		
15	0		
0			
0			
0			
0			
0			
total 3 =	299		

Annex 1 Data sheet for putting in data of counted pods in a farm

Field n°	55							Farmers name	Moutono Francois												
								A = x+y+z	x	y	z		A = x+y+z	x	y	z		A = x+y+z	x	y	z
	Height (m)	DBH (cm)1	DBH (cm)2	DBH (cm)3	DBH (cm)4	Architecture	Passage 1 peinture :Blue date:10/06/2014	Nb total de cabosses mûres	*Nb cabosses mûres saines*	*Nb cabosses mûres pourries*	Nb cabosses rongées	Passage 2 peinture :Red date:10/06/2014	Nb total de cabosses mûres	*Nb cabosses mûres saines*	*Nb cabosses mûres pourries*	Nb cabosses rongées	Passage 3 peinture :white date: 25/08/2014	Nb total de cabosses mûres	*Nb cabosses mûres saines*	*Nb cabosses mûres pourries*	Nb cabosses rongées
Cocoa tree 1	5.7	8.5				5		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 2	5.75	13.5				2		1	1	0	0		0	0	0	0		0	0	0	0
Cocoa tree 3	3.75	7.5				2		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 4	6.55	11	9.5			3a		2	1	0	1		0	0	0	0		0	0	0	0
Cocoa tree 5	6.25	11				2		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 6	4.95	6	4			3a		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 7	5.35	6				2		3	2	0	1		0	0	0	0		0	0	0	0
Cocoa tree 8	5.5	8.3				5		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 9	5.3	8	2.3			4		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 10	4.9	9				5		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 11	2.9	4.5	3.2			3a		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 12	3.9	3.5				5		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 13	5.7	10	6.5			4		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 14	5.3	7.5				5		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 15	6.1	7.3	11			4		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 16	5.85	6.2	8			4		1	1	0	0		0	0	0	0		0	0	0	0

Annex 2 Data sheet for putting data on architectural type, number of ripe pods per tree and per plot



Annex 3 Canker accumulation on stem of cocoa due to mired attacks.

Correlation matrix (Pearson) :

Variables	Potential Yield (kg/ha	ees density	ciated trees	ciated trees	ted trees der	area cacao (n	a DBH < 30cm	a DBH >30cm	ea ass. Trees	basal area (m	ight of cocoa	eight of ass. t	oa C stock (t/	30 diam C st	30 diam C st	trees total C	l C in trees (t,
Potential Yield (kg/ha)	**1**	0.244	0.237	-0.268	0.193	**0.469**	0.031	-0.109	-0.104	0.040	**0.282**	-0.146	**0.446**	0.069	-0.123	-0.117	-0.077
cacao trees density (ind/ha)	0.244	**1**	**0.592**	-0.114	**0.585**	0.127	0.009	-0.143	-0.141	-0.099	**-0.366**	**-0.527**	0.009	-0.059	-0.194	-0.199	-0.196
DBH < 30 cm associated trees density (ind/ha)	0.237	**0.592**	**1**	-0.222	**0.984**	-0.197	**0.420**	-0.198	-0.139	-0.196	**-0.467**	**-0.680**	**-0.307**	**0.271**	-0.210	-0.187	-0.212
DBH > 30 cm associated trees density (ind/ha)	-0.268	-0.114	-0.222	**1**	-0.043	-0.263	0.027	**0.711**	**0.710**	**0.616**	0.028	**0.268**	-0.208	0.053	**0.636**	**0.640**	**0.617**
Total associated trees density (ind/ha)	0.193	**0.585**	**0.984**	-0.043	**1**	-0.250	**0.436**	-0.072	-0.012	-0.088	**-0.473**	**-0.648**	**-0.353**	**0.287**	-0.098	-0.074	-0.104
Basal area cacao (m2/ha)	**0.469**	0.127	-0.197	-0.263	-0.250	**1**	-0.247	-0.054	-0.087	0.218	**0.648**	0.197	**0.978**	-0.149	-0.006	-0.018	0.067
Basal area DBH < 30cm (m2/ha)	0.031	0.009	**0.420**	0.027	**0.436**	-0.247	**1**	-0.022	0.114	0.037	-0.191	**-0.349**	-0.262	**0.945**	-0.069	0.011	-0.012
Basal area DBH >30cm (m2/ha)	-0.109	-0.143	-0.198	**0.711**	-0.072	-0.054	-0.022	**1**	**0.991**	**0.954**	0.132	**0.542**	0.012	0.036	**0.962**	**0.963**	**0.957**
Basal area ass. Trees (m2/ha)	-0.104	-0.141	-0.139	**0.710**	-0.012	-0.087	0.114	**0.991**	**1**	**0.953**	0.105	**0.491**	-0.024	0.163	**0.946**	**0.958**	**0.949**
Total basal area (m2/ha)	0.040	-0.099	-0.196	**0.616**	-0.088	0.218	0.037	**0.954**	**0.953**	**1**	**0.299**	**0.541**	**0.273**	0.115	**0.925**	**0.933**	**0.950**
Mean height of cocoa trees (m)	**0.282**	**-0.366**	**-0.467**	0.028	**-0.473**	**0.648**	-0.191	0.132	0.105	**0.299**	**1**	**0.517**	**0.756**	-0.019	0.157	0.156	0.220
Mean height of ass. trees (m)	-0.146	**-0.527**	**-0.680**	**0.268**	**-0.648**	0.197	**-0.349**	**0.542**	**0.491**	**0.541**	**0.517**	**1**	**0.303**	-0.198	**0.592**	**0.574**	**0.596**
Cocoa C stock (t/ha)	**0.446**	0.009	**-0.307**	-0.208	**-0.353**	**0.978**	-0.262	0.012	-0.024	**0.273**	**0.756**	**0.303**	**1**	-0.144	0.055	0.043	0.130
Ass tree < 30 diam C stock (t/ha)	0.069	-0.059	**0.271**	0.053	**0.287**	-0.149	**0.945**	0.036	0.163	0.115	-0.019	-0.198	-0.144	**1**	-0.018	0.066	0.053
Ass tree > 30 diam C stock (t/ha)	-0.123	-0.194	-0.210	**0.636**	-0.098	-0.006	-0.069	**0.962**	**0.946**	**0.925**	0.157	**0.592**	0.055	-0.018	**1**	**0.996**	**0.994**
Associated trees total C stock (t/ha)	-0.117	-0.199	-0.187	**0.640**	-0.074	-0.018	0.011	**0.963**	**0.958**	**0.933**	0.156	**0.574**	0.043	0.066	**0.996**	**1**	**0.996**
Total C in trees (t/ha)	-0.077	-0.196	-0.212	**0.617**	-0.104	0.067	-0.012	**0.957**	**0.949**	**0.950**	0.220	**0.596**	0.130	0.053	**0.994**	**0.996**	**1**

The values in bold are different from 0 at a level of significance of alpha=0.05

Annex 4 Pearson's correlation matrix

	Field n° 1					
	Farmers name			biedi		
Tree						
N° ind	*scientific or local name*	Productive/ unproductiv e (Y/N)	Reason if unproductiv e	production	unit of production	equivalent inkg MS
1	*D edulis*	y		1	bassin	22
2	*D edulis*	y		5	bassin	22
3	*D edulis*	y		2	bassin	22
4	*D edulis*	y		1	bucket	22
5	*D edulis*	y		1	bucket	22
6	*D edulis*	y		1	bucket	22
7	*D edulis*	y		2	bassin	22
8	*Citrus s*	y		1	bassin	30
9	*Citrus r*	N	not known			
10	*P americana*	y		5	bassin	35
11	*P americana*	y		2	bassin	35
12	*P americana*	y		2	bassin	35
13	*P americana*	y		2	bassin	35
14	*lime*	Y		3	bucket 15l	15kg
15	*Citrus s*	N	young			
16	*Citrus s*	N	young			
17	*Citrus s*	N	young			
18	*Citrus s*	N	young			
19	*Citrus s*	N	young			
20	*Citrus s*	N	young			
21	*Cola n*	y		1	bucket 10l	10kg
22	*Cola n*	N	not known			
23	*Mangifera i*	N	killed			30
24	*Mangifera i*	N	killed			

Annex 5: Data sheet for inventory of associated fruit tree species