REPUBLIC OF CAMEROON
Peace-Work-Fatherland

THE UNIVERSITY OF DSCHANG

FACULTY OF AGRONOMY AND AGRICULTURAL SCIENCES

REPUBLIQUE DU CAMEROUN
Paix-Travail-Patrie

UNIVERSITE DE DSCHANG

FACULTE D'AGRONOMIE ET DES SCIENCES AGRICOLES

DEPARTMENT OF CROP SCIENCE

DEPARTEMENT D'AGRICULTURE

EFFECT OF SHADE TREES ON COCOA YIELD IN SMALL-HOLDER COCOA (*Theobroma cacao*) AGROFORESTS IN TALBA, CENTRE CAMEROON

Thesis presented in partial fulfillment of the requirements for the award of an INGENIEUR AGRONOME Degree

By,

TARLA JUSTIN NGALA

Ingénieur des Travaux Agricoles

Option: Crop Science

CM04-09ASA0108

June 2015

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CERTIFICATE OF ORIGINALITY

I, TARLA Justin NGALA, attest that this thesis is the fruit of my personal work carried out within the framework of Agroforestry Systems for Food (AFS4FOOD) project at the Centre International de Recherche Agronomique pour le Développement (CIRAD) under the field supervision of Dr. Ing. Stephane Saj (CIRAD), under the academic supervision of Prof. MVONDO AWONO Jean Pierre and Dr. BEYEGUE DJONKO Honoré, Associate Professor and Senior Lecturer in the Department of Crop Science, Faculty of Agronomy and Agricultural Sciences of the University of Dschang, respectively.

This document is authentic and has not been presented for the award of any degree.

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Co-Supervisor | Supervisor

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The Head of Department

Date: …/...…/…....

DEDICATION

This piece of work is dedicated to my dear parents Mr. and Mrs. Ngwa for their love, care, prayers, moral and financial disbursement in my life and my academic career.

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All glory and honour goes first to the heavenly father for giving me life, strength, wisdom and keeping me strong since from birth up to the point of realizing this piece of work.

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ABSTRACT

Agroforestry systems in humid tropical areas are complex multispecies cropping systems whose overall performances are often hard to assess. The objectives of a farmer to improve farm performance by increasing productivity through shade removal and chemical inputs are sometimes in direct opposition with the goals of sustainability to conserve livelihood. This study was conducted from April to October 2014 in Talba village, located in the Mbam and Kim division in the Centre Region of Cameroon with aim to study the effect of shade trees on cocoa yield in these agroforestry systems to come out with appropriate system that favours better yield and conserves biodiversity. The methodological approach used here consisted in the realization of 55 plots having a dimension of 40 m x 20 m (800 m^2) in a cocoa based agroforestry system with 15 plots under full sun, 15 in a simple system and 25 in a complex system. In each sampled plot, developed cocoa pods were counted for yield evaluation for each system. Other information in cocoa plots like cocoa height, cocoa architecture, and diameter were also considered for evaluation of yield variables like basal area and density. The results obtained at the end of this study gave an average potential yield value in Talba of 1178.5 kg/ha which showed a significant difference with respect to plot system but no significant difference with respect to age of plot. Regarding plot system, highest potential yield was recorded in the simple system with value of 1470.5 kg/ha. The highest yield was obtained in the age group 10 to 20 years with value of 1614.8 kg/ha. Potential yield showed significant increase with cocoa tree basal area and density. Potential yield showed a poor correlation with mean height of cocoa tree and a negative correlation with basal area of associated trees, diameter at breast height of associated trees and density of associated trees. It can therefore be concluded that cocoa yield greatly depends on the farm system, cocoa tree structure and field density.

Keywords: potential yield; agroforestry systems; biodiversity

RÉSUMÉ

Les systèmes agroforestiers dans les zones tropicales humides sont les systèmes de cultures multispécifiques complexe dont les performances globales sont souvent difficiles à determiner. Le but d'un agriculteur d'améliorer la performance agricole en augmentant la productivité grâce à l'abolition de l'ombre et utilisations des produits chimiques est parfois en affrontement directe avec les objectifs de durabilité pour conserver les moyens de subsistance. Cette étude date d'avril à octobre 2014 au village Talba, situé dans le department du Mbam et Kim dans la région du centre Cameroun, avait pour cible d'étudier l'effet des arbres d'ombrage sur le rendement du cacao dans le système agroforestier pour sortir un système approprié qui assure un meilleur rendement et qui conserve la biodiversité. L'approche méthodologique utilisée ici consisté a la réalisation de 55 parcelles ayant une dimension de 40 m x 20 m (800 m²) dans un système agroforestier à base de cacao, avec 15 parcelles en plein soleil, 15 dans un système simple et 25 dans un système complexe. Dans chaque placette, les cabosses de cacao développées ont été comptées pour l'évaluation de rendement pour chaque système. Par ailleurs, autres informations dans les parcelles de cacao comme la hauteur du cacaoyer, l'architecture du cacaoyer, et le diamètre ont été aussi prise en compte pour l'expertise des variables de rendement comme la surface terrière et la densité. De ce fait les résultats obtenus à la fin de cette étude ont donné une valeur de rendement potentiel moyenne à Talba de 1178,5 kg/ha qui ont montré une différence significative par rapport au système du champ, mais aucune différence significative quant à l'âge de la parcelle. En ce qui concerne le système de parcelle, le plus haut potentiel de rendement a été enregistré dans le système simple avec une valeur de 1470,5 kg/ha. Alors que le rendement le plus élevé a été obtenu dans la tranche d'âge de 10 à 20 ans avec une valeur de 1614,8 kg/ha. De plus, le rendement potentiel a montré une augmentation significative avec surface terrière du cacaoyer et la densité. En outré le rendement potentiel a demontré une faible corrélation avec la hauteur moyenne d'arbres de cacao et une corrélation négative avec la région basale des arbres associés, le diamètre à hauteur de poitrine d'arbres associés et la densité des arbres associés. En vu de tout ceci, nous pouvons donc conclure que le rendement de cacao dépend fortement du système du champ, la structure d'arbre de cacao et la densité.

Mots-clés: rendement potentiel; systèmes agroforestiers; la biodiversité

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LIST OF ABBREVIATIONS

AGB:	Above Ground Biomass
AFS4FOOD:	Agroforestry Systems for Food
ANOVA:	Analysis of variance
BGB:	Below Ground Biomass
CF:	Carbon fraction
CIRAD:	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
COMIFAC:	Commission Des Foret d'Afrique Centrale
CPB:	Cocoa Pod Borer
CRDT:	Centre Rural de Développement de Talba
FAO:	Food and Agricultural Organization
FAO STAT:	Food and Agricultural Organization Statistics
FASA:	Faculté d'Agronomie et des Sciences Agricoles
FIDA:	Fond international pour le développement agricole
GCRAI:	Groupe consultatif pour la recherche agricole internationale
GERDAT:	Groupement d'Etude et de Recherche pour le Développement de l'Agronomie Tropicale
GFAR:	Global Forum on Agricultural Research
ICCO:	International Cocoa Organization
ICRAF:	International Centre for Research in Agroforestry
IPM:	Integrated Pest Management
IRAD:	Institut de Recherche Agricole pour le Développement
ITTO:	International Tropical Timber Organisation
VSD:	Vascular-streak dieback
WP:	Work package

CHAPTER 1: INTRODUCTION

1.1. BACKGROUND AND JUSTIFICATION OF STUDY

The cocoa tree (*Theobroma cacao* L) is highly prized for its beans from which cocoa powder and butter are produced. In the past 30 years, world production tripled to a record of 3.7 million tonnes of dry cocoa beans in 2008 and generated an estimated US$ 7.4 billion of income for millions of smallholder farmers (ICCO, 2008).

In Africa, the introduction of cocoa was from the Islands of Sao Tome, introduced in Ghana in 1879, Cocoa was introduced in Cameroon in 1886 by the German colonial administration (Sonwa *et al.*, 2007). In the mid 1920s, cocoa cultivation has shifted from plantations owned by foreigners to indigenous growers who are mainly smallholders (Gockowski and Dury 1999) and practiced in areas where land pressure is not very high (forest zone, savannah zone, forest - savanna transition zone). About 80% of cocoa production in Cameroon is in three regions namely the South West (35%), the Centre (28%) and the South (16%) and accounts for around 6% of Cameroon's exports, and is of crucial importance for the economy (Bisseleua, 2007). An estimated 450 000 rural households (more than a third of the total number of rural households) earned the larger part of their cash income from cocoa (Sonwa *et al.*, 2001, Gockowski and Ndoumbe 2004).

The total acreage under cocoa cultivation in Cameroon was estimated to about 420 000 hectares with current production level averaging 168 000 metric tonnes per annum (ICCO, 2005) and aims at raising this to 300 000 metric tonnes by the year 2010. However, despite the economic importance of cocoa and farmers' sustained interest in production, yields of cocoa continue to be below 300 kg/ha on average. Reasons for the low productivity are the ageing of the trees (mainly in Southern Cameroon where 40% of cocoa trees were planted before 1960), poor farm maintenance practices, planting of low yielding varieties, ravages caused by pests' such as mirids (*Salhbergella singularis* H.) (Mpé, 2002). Diseases (*Phytophthora* species: *P. megakarya*; causing 80-90% losses without chemical control) (Gregory *et al.*, 1985; Nyasse, 1992; Bisseleua, 2007) and poor soil fertility caused by prolonged cultivation on farmlands also contribute to this low productivity. Farmers of Southern Cameroon have developed a system in which cocoa trees are intimately associated with local and exotic tree species (Losch *et al.*, 1991; Gockowski *et al., 2004*), which is the case in other cocoa growing regions in Cameroon.

Cocoa agroforests in Cameroon like elsewhere generally result from the clearing of some large forest trees in either secondary or primary forests and the thinning of part of the under storey in order to introduce young cocoa plants (Kenta, 2010). Other large trees are left during the establishment of the agroforest and crops such as banana and plantain are used to shade the cocoa seedlings. As the plantation becomes older, the forest tree stumps allows some native trees to regenerate, while some useful exotic and local tree species are introduced by the farmers. The retention of forest trees and the introduction of native and exotic plants determine the composition and structure of the cocoa agroforests. The result is generally a multi-strata (complex) and multi-species agroforest whose species composition reflects the needs of the local people or farmers and this then shows the gap between assumptions of researchers and the actual practice of local people through a case study of cocoa production in Cameroon (Kenta, 2010).

The Centre International de Recherche Agronomique pour le Développement (CIRAD, 2012), states that the technical model proposed to farmers generally gives priority to the intensive management of cocoa as a single crop or with light shade. With this model, yields are high during the first years of cocoa cultivation. However, after 30 to 40 years, yields collapse because of the lack of mineral fertilization. On the contrary, in the centre region of Cameroon, where 80% of cocoa plantations are over 40 years old (CIRAD, 2012), farmers manage to obtain cocoa yields, which though lower than for an intensive model, are maintained over a much longer time period with no fertilizer inputs.

In the Centre region of Cameroon, trees in cocoa agroforests have many more uses for local farmers than just providing a suitable microclimate for cocoa trees and farmers prefer trees that bear edible produce of economic importance. The drop of cocoa prices during the 1990s in Cameroon have encouraged farmers to diversify their income by maintaining and introducing useful species (such as timber species, medicinal species and fruit trees) in their cocoa agroforests (Sonwa, 2004). Cocoa cultivation therefore requires enough space, which is often made available to the detriment of forest areas as it is usually performed after destruction of the forest, and is considered one of the reasons for deforestation in the tropics coupled with slash and burn, wood logging and dramatic city expansion. Between 1990 and 2010, Cameroon lost an average of 220 000 ha per year. In total, between 1990 and 2010, Cameroon lost 18.1% of its forest cover or around 4 400 000 ha (FAO, 2012).

Faced with these multiple problems caused by the concern for expansion of agriculture, agroforestry, which is the intimate combination of the cultivation of tree species and agricultural crops like cocoa is positioned as a solution that can accommodate both the problem of food security, biodiversity conservation and environmental protection.

In Cameroon, cocoa-based agroforestry systems vary from the most simple to the most complex in terms of structure where the complex or multi-strata systems are tree dominated land use systems with two or more strata of trees or shrubs and a substantial degree of structural complexity within at least one of the strata with high number of components. There is also a simple or two-strata system which is represented by associations of a small number of components, usually not more than five tree species and an annual species. These simple agroforestry associations represent what can be called the "classical" agroforestry model as it is the most favoured in research and development program of most institutions dealing with agroforestry (Nair, 1989).

Agroforestry is not a new method or a revolutionary way of farming. In fact, this is one of the oldest methods of agricultural production, but it was abandoned for a while because of the intensification of modern agriculture (Nair, 2007). Furthermore, shading trees can be maintained in cocoa-based agroforestry systems to reduce pest attacks (Beer *et al.*, 1998) for stabilizing the microclimate (Sporn *et al.*, 2009) for soil protection against rain drops (Dietz *et al.*, 2005). In the scientific literature, there is consensus that cocoa-based agroforestry systems with dense and diverse shade tree stands do harbor high levels of species richness (Jagoret, 2011). Above all, the aim is not only to sustain the forest in cocoa growing areas but also to increase the income of the small-scale cocoa farmers.

In the context of Agroforestry Systems for Food (AFS4FOOD) project under which this study was carried out, one of the key objectives is to improve food security and well-being of African rural households through agroforestry, this directly via the various types of edible plant, medicinal plants, wood and other non-timber products, and indirectly through the sustainable provision of environmental service like sequestration and storage of carbon by woody component (cocoa, fruit trees, forest trees) in cocoa-based agroforest. Here, the attention of cocoa yield evaluation in a cocoa-based agroforestry system is drawn to come out with a better and sustainable system for cocoa production while protecting the environment and conserving biodiversity. The choice for a study of the effect of shade trees on cocoa yield in a cocoa-based agroforestry system is because despite ecological interest of cocoa, there has been little research on this cocoa-based agroforestry model with regards to its productivity.

1.2. PROBLEM STATEMENT

Deforestation, which can be either for agricultural or city expansion need is considered one of the main environmental problems in the tropics. Agroforestry is a means to address this case of deforestation for farming need like for cocoa growing. The problem posed by these cocoa-based agroforestry systems is that the output of the farmer compared with other systems is not known. Also, how other factors like cocoa density, cocoa basal area and age of farm affects yield is not known despite the numerous advantages of this system like high carbon storage and sequestration, lower field pest pressures, microclimate stabilization and its maintenance over a much longer time period without fertilizer applications (CIRAD, 2012). This therefore calls for yield evaluation in this system which is of great importance. Reduction of carbon dioxide emission, principal greenhouse gas remains a major challenge for every nation nowadays. At the national and international levels, climate policy, and agricultural development policies have powerful impacts on poverty, livelihoods, greenhouse gas emissions, and overall food, human, and environmental security. Improved understanding of these impacts, and the implementation of appropriate policies based on this understanding, would generate improved outcomes that would have major impacts on human welfare and environmental sustainability.

According to Somarribba (2013), since cocoa yields decrease non-linearly with increasing shade, a need is to design optimal cocoa agroforestry systems with high yields and high carbon stocks. Moreover, the presence of shade trees is often assumed to negatively affect growth and yield of cocoa plants through competitive water use (Dietrich, 2010).

With the complex system, farmers manage to obtain cocoa yields, which though lower than for a monoculture system, are maintained over a much longer time period with little or no fertilizer inputs. The research question in the study may be framed as:

What is the effect of shade trees on cocoa yield in these cocoa-based agroforestry systems?

To attempt a response to such question, one asks more specific questions such as:

- what is the effect of cocoa field age and system on yield in Talba?
- what is the cocoa tree density variation for the different systems?

1.3.OBJECTIVES OF STUDY

This research piece of work seeks to define and appreciate the effect of shade trees on cocoa yield in a cocoa-based agroforestry system in the Centre region of Cameroon in a perspective to design a better system for cocoa production which is productive, sustainable, conserves biodiversity, less costly and adapts with the growing population.

More specifically, this study seeks to,

- identify and characterize cocoa based agroforestry system in the zone;
- evaluate yield of cocoa in both agroforest and no shade farms;
- identify the ages of cocoa fields in the study area and;
- propose a better structure for cocoa production.

1.4. IMPORTANCE OF STUDY

Many research works have been carried out in the domain of cocoa based agroforestry systems in Cameroon. The peculiarity of this study is to come out with scientific prove of the effect of shade trees on yield of cocoa in a cocoa based agroforestry system in the village Talba which is the first of such yield evaluation in this area. The output from this investigation will better inform on cocoa yield variation in the long term and according to companion tree density, in the study area in particular and the Centre region of Cameroon as a whole.

CHAPTER 2: DEFINITION OF CONCEPTS AND LITERATURE REVIEW

2.1. DEFINITION OF CONCEPTS

2.1.1. Agroforestry

Agroforestry is defined as "the combination of forest trees with crops, or with domestic animals, or both" (Combe, 1982). Agroforestry is a land use management system in which trees or shrubs are grown around or among crops or pastureland. It combines agricultural and forestry technologies to create more diverse, productive, profitable, healthy, and sustainable land-use systems (James *et al.*, 2014)

2.1.2. Agroforestry system

Agroforestry systems include both traditional and modern land-use systems where trees are managed together with crops and/or animal production systems in agricultural settings. The presence of trees on external and internal boundaries, cropland, homestead plots or on any other available niche of farmland, defines the agroforestry systems structurally (Agroforestry Systems, 1982)

2.1.3. Deforestation

Deforestation is defined as the conversion of forest to another land use or the long-term decline of forest cover (canopy) below the minimum threshold of 10% (FAO, 2006). Its causes are many and vary from one country to another with some examples like population pressure, poverty, and agriculture.

2.1.4. Forest degradation

It is considered as a process of change within the forest that negatively affects its characteristics (Simula, 2009). It also refers to the reduction of the capacity of a forest to produce goods and services (ITTO, 2002). Capacity includes maintaining the structure and ecosystem functions (ITTO, 2002). A degraded forest provides only a limited amount of goods and services and maintains only limited biological diversity. It lost its structure, function, species composition and / or productivity normally associated with natural forests (ITTO, 2002).

2.1.5. Sustainability

In ecology, sustainability refers to how biological systems remain diverse and productive over time (James *et al.*, 2014). In Environmental science, it is defined as the quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance (James *et al.*, 2014).

2.1.6. Biodiversity

Biological diversity means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Convention on Biological Diversity, 2011).

2.1.7. Shade trees

These are trees that with its applications, crops are purposely raised under tree canopies and within the resulting shady environment. For most uses, the understory crops are shade tolerant or the over storey trees have fairly open canopies. A conspicuous example is shade-grown cocoa and coffee. This practice reduces weeding costs, mirid attack in cocoa and increases the quality and taste of the coffee.

2.2. LITERATURE REVIEW OF COCOA

2.2.1. Origin and distribution

The genus *Theobroma* originated in the Amazon and Orinoco basins, and subsequently spread to Central America, particularly Mexico, where it was known and used by the local population. The Olmec and Mayas, and later the Toltecs and Aztecs considered it the "food of the gods" (Pohlan and Perez, 2012). In the 16^{th} century, Spanish explorers were the first to bring cocoa beans to Europe. Nowadays, cocoa has become one of the most important cash crops and it is a key ingredient for many sweets and cosmetics. Since the discovery by Europeans, the tree quickly spread and has become important throughout the humid tropics (ICCO, 2008).

Theobroma has been divided into twenty-two species of which *T. cacao* is the most widely known. It was the Maya who provided tangible evidence of cacao as a domesticated crop (ICCO, 2013). Archaeological evidence in Costa Rica indicates that cacao was drunk by Maya traders as early as 400 BC. The Aztec culture, dominant in Mesoamerica from the fourteenth century to the Conquest, placed much emphasis on the sanctity of cacao. The first outsider to drink chocolate was Christopher Columbus, who reached Nicaragua in 1502 searching for a sea route to the spices of the East. But it was Hernan 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. The drink was initially received unenthusiastically and it was not until sugar was added that it became a popular drink in the Spanish courts (ICCO, 2013). There are thousands of clones of cacao in field gene banks in different areas of the world. Some of the largest collections are at the Cocoa Research Institute in Tafo, Ghana (6,000 accessions), the International Cocoa Genebank in Trinidad (1,872 accessions), and CEPLAC in Brazil (1,749 accessions). The Tropical Agriculture Research Station, in Mayaguez, Puerto Rico, has 372 accessions (Brunner *et al*., 2007)

2.2.2. Classification

Theobroma cacao belongs to the plant kingdom, *magnoliophyta* division in the *magnoliopsida* class, under *malvale* order in the family *malvaceaes* (Purseglove *et al*., 2012). Cacao types are classified into three main groups: Criollo, Forastero and Trinitario. Criollo cacao developed in northern South America and Central America, and has thin wall, red or yellow fruits. The seeds are large, round, white or pale purple, not astringent, and produce the highest quality chocolate. Unfortunately, Criollo types are low yielding and susceptible to many diseases, and are rare in cultivation. Forastero cacaos are from the Amazon Basin, and have a thick wall, smooth, usually yellow fruit. The seeds are flattened and purple in color. Forastero cacaos are very productive, and dominate the world cacao production. Trinitario cacaos arose in Trinidad as hybrids of Criollo and Forastero types (see Annex 1). They are highly variable, and considered high quality for chocolate production (Montoso Gardens, 2007). There are approximately 22 *Theobroma* species, and about 15 are utilized for their edible pulp or seeds. *Theobroma cacao* is the most important specie within the genus *Theobromae*. *Theobroma grandiflorum* (cupuassu), *Theobroma gileri* (mountain cocoa), *T. bicolor* (macambo) and *T.*

subincanum (wild cocoa) are other species utilized for their sweet, edible pulp and edible seeds. (Brunner *et al*., 2007)

2.2.3. Description

The cocoa plant is a medium-sized tree, reaching 20-30 feet (4-8 m) tall. Branches are produced in groups of three to five. The leaves are simple, 4-8 inches (10-20 cm) long, light to dark green and soft and flexible. New growth is bright red or pink. Small whitish flowers are produced on the branches and trunk, singly or in groups of 3-5. Fruits are 5-10 inches (13-26 cm) in length and 2-3 inches (5-7.6 cm) in diameter. The fruit has a hard shell which may be smooth or ridged, elongated or rounded, red, yellow, or orange, and contains between 20-50 seeds, surrounded by a cream colored, sweet-sour, aromatic pulp (Brunner *et al*., 2007).

The original habitat of the cocoa plant is a tropical forest with a canopy of tall trees, rainfall and humidity is high, so the plants grow tall. In the garden, plant height at 3 years can reach 1.8 - 3 meters and at the age of 12 years reached 4.5 - 7 meters. Cocoa plant is dimorphous (two forms have branches), that is, orthotrop branches (branches that grow upward) and plagiotrop (branches that grow sideways). Cocoa is a plant with feeder root surface (mostly developing lateral roots near the soil surface). Thickness of rooting zone in the good soil is 30-50 cm. At low soil water soils, roots grow long and riding the lateral roots into the soil, whereas at high soil water and clay soils, the roots do not grow up riding so deep and lateral roots grow near the soil surface (Arno *et al.*, 2011).

2.2.4. Ecology

Mean minimal temperatures of less than 21 °C is not suitable for cocoa cultivation (Braudeau, 1969; Pedelohore, 2012). Average rainfall of 1250-3000m per annum and preferably between 1500-2000 m with a dry season of not more than 3months with less than 100mm rain per month is deal but the quantity is less important than distribution. Rainfall can be supplemented with irrigation during dry months. Temperature varying between 30-32 °C mean maximum and 18-21 °C mean minimum but around 25°C is considered to be favourable. Humidity is uniformly high in cocoa growing areas, often 100% at night falling to 70 or 80% by day sometimes during the dry season. The most marked effect was on leaf area, plants growing at low humidity (50-60%) having larger and greater leaf area than plants growing at medium (70-

80%) and high (90-95%) humidity under the latter conditions leaves are smaller and tend to be curled and withered at the top. The other effect of humidity concerns the spread of fungal diseases and the difficulties of drying and storage. Cocoa is a tap-rooted plant and grown on a wide range of soil types and the standards for soil suitable for cocoa vary considerably. The best soil for cocoa is that which is rich in humus, deep well-drained soils free from iron concentrations and high in nutrient content (Opeke, 2005; Onakoya, 2011).

The cacao tree is a shrub undergrowth native of the Amazon rainforest and can grow well in a very dense shade. It is now shown that the shading is a limiting factor of production and should be maintained to pass more than 50% of light (Mossu *et al*., 1990).

2.2.5. Seed production

Cocoa seeds readily germinate when sown and do not pass through a dormancy period. For raising seedlings, seeds of mature pods are taken from high yielding mother plants. The mother plants selected should have medium or large green pods with an average dry bean of not less than one gram. A more suitable procedure for planting good quality seedlings is to collect hybrid seeds from biclonal or polyclonal seed garden involving superior self-incompatible parent (Onakoya, 2011). They lose viability on extraction from the pod within five to seven days, unless specially treated. Cocoa seeds are therefore best stored in pods where they remain viable for up to four weeks after harvesting. If it is therefore necessary to extract the seeds from the pods for storage, the extracted seeds should be mixed with moist fine sand, moist sawdust or moist ground charcoal. The mixture should therefore be stored in a cool dry place and under such conditions; extracted seeds can be stored for two to three weeks (Onakoya, 2011).

2.2.6. Planting

Each seed is sown in a bag whose land has been copiously watered the previous day. The seed is placed flat on the surface and middle of the bag, then pushed down to a centimeter in depth and covered with soil. Another watering is done immediately after planting; watering can contains a pre-emergent herbicide containing for example Diuron (15 g of commercial product at 80% in 100 liters of water for 2 500 bags). The nursery is the place where the seeds are germinated and where seedlings are raised for five to seven months, sometimes more, for their field planting. The nursery should be established on a flat surface or slightly sloping area, well drained and not flooded, close to a permanent water source, close to a passable road and as close as possible to the planting site. In areas where wind can be strong, installing the nursery too close to the forest edge should be avoided (Mossu *et al*., 1990).

The location should be cleared of all vegetation, the soil thoroughly cleaned and, if necessary, drainage ditches dugged in the direction of steepest slope. A frame stakes, in wood or bamboo, 3 m high, should be built to support some 2.5 m above the ground shading passing about 50% of the total luminosity. Such shading can be easily obtained using fronds. They will dry slowly and allow a gradual transition from any external light, which acclimatize and harden the young seedlings before field planting. In many countries, the shade of the nursery is provided by various permanent crops such as rubber, palm oil or *Gliricidia sp*. Lateral protection is often required to complete the shade if the place is very clear and to avoid any depredation animals. There should be an area of 80 m^2 nursery for seedlings required for planting a hectare (Mossu *et al*., 1990). Diseased plants and plants with twisted tap-root should be thrown away and planting should be done in a day when the soil is moist and when the sky is cloudy (FAO, 2006).

2.2.7. Insect pests

2.2.7.1. Mirids

The mirid (*Sahlbergella singularis)* is one of the primary pests affecting cocoa (*Theobroma cacao* L.) production in Africa associated with 25 to 40% production losses. *Sahlbergella singularis* is widely distributed in West Africa, present throughout the forest zone, from Sierra Leone to the Demographic Republic of Congo, and its life history is well known on cocoa. However, knowledge of S. singularis population structure in cocoa plantations is incomplete. About one century ago, mirids adapted to cocoa, a newly introduced cash-crop in West Africa. Its natural host-plants are mainly forest trees of the Malvaceae (Chapuis *et al*., 2012).

Mirids also known as capsids are insects that use their needle-like mouthparts to pierce the tissues of cocoa trees and suck the sap. During this process they may inject toxic saliva into the plants. Infestation on cocoa pods results in minor direct losses. However, the holes created on the pods during feeding often make the pods vulnerable to black pod, which often cause more losses than the mirid itself. Moreover, attacks on shoots and young branches reduce the canopy of a tree and the tree becomes susceptible to other pests and diseases. Young trees can die within a year if the attack is serious and even mature trees can be affected very severely. Losses can be as high as 30% or more if infestation is severe (David, 2005; Ebewore *et al.*, 2013).

The most common species in Ghana and West 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%. Cocoa mirids pierce the surface of cocoa stems, branches and pods, killing the penetrated host cells and producing unsightly necrotic lesions (ICCO, 2013).

2.2.7.2. Cocoa pod borer (CPB)

Cocoa pod borer (*Conopomorpha cramerella*) is a pest of cocoa in South-East Asia. It first appeared in Sabah, Malaysia, in 1980, but at that time there was no quantitative information on the damage it could cause (Roger, 2003).

Cocoa pod borer (CPB) causes losses to cocoa by boring through the wall and into the pod, feeding on the pulp of bean and placenta of the pod. Damage to the funicles of pods results in malformed and undersized beans, in severe infestation it produce small flat beans that are often stuck together. It also causes the pod to yellow or ripen unevenly and prematurely. The beans from seriously infested pods are completely unusable, and over half the potential crop can be lost in heavy infestations. In light infestations, there may be no economic loss but control is still needed to prevent the development of more serious infestations (Crop Protection Compedium, 2014).

2.2.8. Diseases

2.2.8.1. Witches' Broom

Moniliophthora perniciosa is a fungus responsible for Witches' Broom disease. During the last century the fungus spread throughout all of South America, Panama and the Caribbean, causing great losses in production. The most visible effect can be seen in Brazil where the introduction of the disease in the region of Bahia caused a decrease in production of almost 70% during a period of 10 years (Robert, 1989). The fungus attacks only actively growing tissue (shoots, flowers and pods) causing cocoa trees to produce branches with no fruit and ineffective leaves. The pods show distortion and present green patches that give the appearance of uneven ripening.

The life cycle of the fungus is synchronized with the phenology of the host. One of the most influential factors for the adequate reproduction of the fungus is water. Basidiospores are released at night and are related to the level of humidity of about 80% and favourable temperature comprise between 20 and 30 ºC. The spores are capable of being disseminated locally by water and convection currents and over long distances by wind. Host resistance is recommended as the best option for economic and sustainable control. During the 1930s, selections were identified showing resistance in Trinidad. As a result, Trinidad Selected Hybrids were developed and widely planted during the 1950s. However, more aggressive strains of the pathogen in other countries made these selections ineffective. CEPLAC (Brazil) is currently working on new molecular techniques such as genetic linkage maps and quantitative trait loci to develop new resistant varieties. Various fungicides have been tested showing various results. New compounds and chemicals, which activate the host plant's defences, may offer a more effective and economical control. Phytosanitary pruning is the only effective means of control of Witches' Broom. Complete removal of all infected material is advocated, but it is an impossible task because hidden inoculum sources always remain (Robert, 1989).

2.2.8.2. Frosty pod Rot

Frosty Pod Rot is caused by the basidiomycete *Moniliophthora roreri*. It is found in all north-western countries in South America. First reports of the disease date back to the end of the 19th century, where its aggressive effects caused devastation in Colombian and Ecuadorian cocoa plantations. The fungus has now spread all over the Latin American region, causing significant losses in production, even resulting in the abandonment of cocoa farms (Taylor, 1998; Adejumo, 2004). The fungus infects only actively growing pod tissues, especially young pods. The time from infection to the appearance of symptoms is about 1-3 months. The most outstanding symptom is the white fungal mat on the pod surface. The large amount of spores produced (44 million spores per cm^2) and the genetic variability endows the fungus with considerable adaptability (Taylor, 1998; Adejumo, 2004).

The dry, powdery form of spores allows the fungus to be dislodged by water, wind or physical disturbance of the pod. Disease incidence varies with cultivar, pod age and rainfall. Generally the greatest production is when rainfall is high. All cocoa species seem to be susceptible to this disease. Some varieties have shown a degree of resistance and field screening has identified clones with low disease severity and incidence. Genotypes which produce their pods during the dry season (unfavourable for the pathogen) escape the disease. The use of copper and organic protectors has proved to reduce the incidence of the disease. Systematic fungicides such as Flutolanil have been found effective, although the use of agrochemicals is not economically sustainable in view of the low prices of cocoa (Olaniran *et al*., 1977; Adejumo, 2004).

2.2.8.3. Phytophthora pod rot

Pod Rot, also known as Black Pod, is caused by the fungus *Phytophthora spp*. Three fungal species of the same genus are responsible - *P. palmivora*, *P. megakarya* and *P. capsici*. The *P. palmivora* causes global yield loss of 20-30% and tree deaths of 10% annually. *P. megakarya* is the most important pathogen in Central and West Africa, known as the most aggressive of the Pod Rot pathogens. *P. capsici* is widespread in Central and South America, causing significant losses in favourable environments (ICCO, 2013). Cocoa cultivation is threatened by many constraints, such as the Phytophthora pod rot (PPR) disease. In absence of any chemical control, cacao pod losses may reach 90 to 100% (Despréaux *et al*., 1988; Nyasse *et al*., 2013), posing to the ongoing research the need to find out resistant cultivars. However, Phytophthora pod rot incidence in farmers' field remains high. This suggests that new resistant progenitors should be detected within the available germplasm in addition to the genotypes recently introduced through international cacao quarantines (Nyasse *et al*., 2013).

One major difference between *P. palmivora* and *P. megakarya*, the most damaging species on cacao, is that the production, maturation, and liberation of sporangia are grouped in a short period of time for *P. palmivora*, and in an extended period for *P. megakarya* (Blaha, 1984; Fontem *et al*., 2006). On a single cacao pod, zoospores can be released from sporangia for over 30 days when infected by *P. megakarya* (Depreaux *et al*., 1987; Fontem *et al*., 2006). Based on this basic difference between the two species, we strongly believe that an effective screening strategy for biocontrol candidates of *P. megakarya* needs to lay emphasis on endophytic strains that could control the production and maturation of sporangia on cacao pods since sporangia and, in turn, zoospores are the major propagules for the dissemination of this fungal disease. The cacao pod is the most important site of the infection cycle of cacao black pod disease in cacao farms. Green cacao pod husk pieces prove to be usable for bio-tests in laboratory conditions. This material presents the advantage of making possible the screening procedure for endophytic biological control candidates of *P. megakarya* at infection of cacao pods, mycelia growth inside infected tissues, and fungal sporulation on infected cacao pods tissues, under laboratory conditions (Fontem *et al*., 2006).

Climatic conditions play an essential role in the start of epidemics, which can only develop in the presence of free water. However, the intensity of the diseases and the speed with which they spread also depend on the susceptibity of the planting material, on cultural practices and on the one or more species of Phytophthora involved (Despreaux, 2004)

Pods can be attacked at any stage of development, and the initial symptoms are small, hard, dark spots on any part of the pod. Internal tissues, including the beans, are colonized and shrivel to form a mummified pod (see Annex 2).

2.2.8.4. Vascular-streak dieback (VSD)

A devastating disease named vascular-streak dieback (VSD) was distinguished from the various dieback syndromes of cocoa induced by environmental factors and insects in Papua New Guinea (PNG) in the 1960s (David *et al*., 2006). It caused heavy losses of mature trees and seedlings planted near older cocoa. The disease was later shown to be caused by a new genus and species of basidiomycete, *Oncobasidium theobromae*. VSD has since been found in most cocoa-growing areas in South and Southeast Asia and PNG, from New Britain in the east to Hainan Island, China in the north and Kerala State, India, in the west. It has been a major problem in the large commercial plantations in West Malaysia and Sabah. It is widespread in Indonesia, including in the fine flavour cocoa plantations in East and West Java, and in the large areas of newer cocoa plantings in Sulawesi. It has also been reported from southern Thailand, Burma, Vietnam, and the southern Philippines. The only known host other than cocoa is avocado, which is also an exotic plant in Southeast Asia and the Pacific. It is believed that the fungus evolved on an as yet unidentified indigenous host in Southeast Asia/Melanesia and transferred to introduce cocoa. Thus, VSD is another example of a new encounter disease in cocoa (David *et al*., 2006).

2.2.9. Uses

Cacao is grown primarily for chocolate production, but the edible pulp is delicious and often consumed in the tropics. Cocoa butter is used medicinally in Brazil for healing bruises, and is used by the cosmetic and pharmaceutical industries. The seeds contain about 2% of the alkaloid theobromine, which is a central nervous system stimulant, similar to caffeine (Brunner *et al*., 2007). Theobromine is used as a diuretic and to lower blood pressure, since it dilates the blood vessels. Dry cacao seeds (also known as "beans") may contain as much as 12-18% polyphenols, known as cocoa polyphenols or cocoa flavonoids. Most of the polyphenols in cacao are epicatechin and catechin, but other catechins and quercetin are also present. Cocoa flavonoids have potent antioxidant activity, and have been shown to scavenge free radicals and inhibit the oxidation of LDL. They may also have anti-inflammatory and immune modulator activities, and may promote cardiovascular and immune health. Cocoa, baking chocolate and milk chocolate all contain polyphenols (Brunner *et al*., 2007).

Table 1: Nutritional composition per 100 g cocoa powder

Biochemical and chemical constituent	**Amount (g)**
Carbohydrate	16.50
Protein	21.50
Fat	11.00
Dietary fiber	34.00
Polyphenols	7.00-18.00
Theobromine	2.50
Caffeine	0.10
Potassium	2.00
Calcium	0.15
Magnesium	0.55
Phosphorous	0.70

CHAPTER 3: MATERIALS AND METHODS

3.1. DESCRIPTION OF THE STUDY AREA

3.1.1. Geographical and administrative situation

The Mbangassina community, located in the Central Province, Mbam and Kim Division, is located between 11°10 and 11°30 East longitudes and between 4°20 and 4°40 North latitude. It covers an area of 438 km², and is bounded to the North by the Ngoro community, to the South by the Sa'a community, to the east by the Ntui community and west by the Bokito and Ombessa communities (Commune de Mbangassina, 2010). It has 19 villages including the Talba village, whose geographical coordinates from the South entrance of the village are: 04°34'421" North latitude and 011°28'333" East longitude (Figure 1).

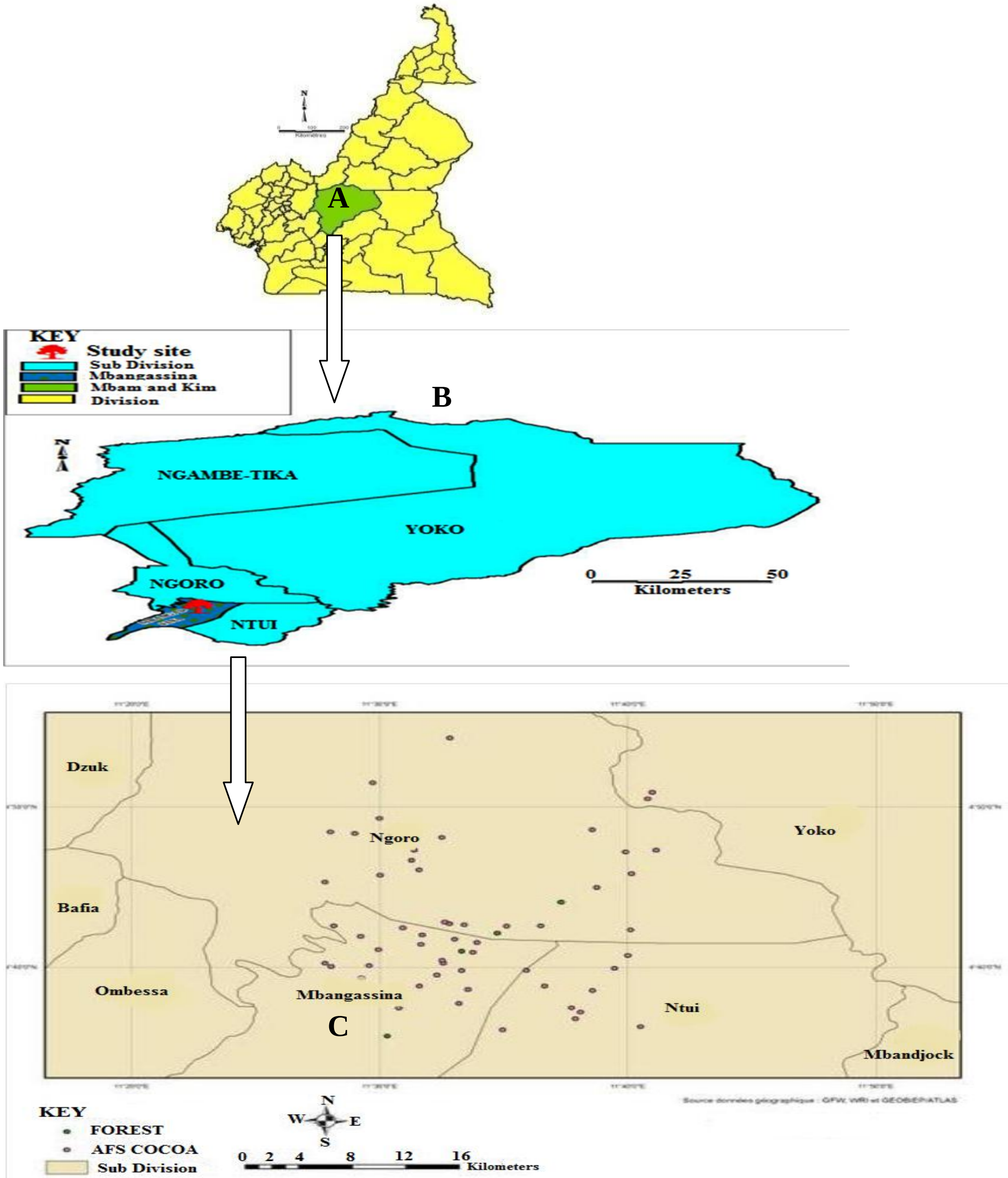

Figure 1: Geographical location of study area

A: Mbam and Kim Division in Cameroon, B: Mbam and Kim Division, C: Mbamgassina in Mbam and Kim Division

Source: Commune de Mbangassina, 2010

3.1.2. Physical milieu

i) Climate

Due to its geographical situation, Talba village falls within the climate area of Equatorial Guinea type, characterized by four seasons. The main rainy season is from mid-August to mid-November, while the short rainy season is from April to June. The long dry season is between mid-November and March and the short dry season between June and July. The annual average temperatures range between 22 ° C and 32 ° C, with a temperature range between 8 ° and 13 ° C. Rainfall between 1300 and 1500 mm per year (Commune de Mbangassina, 2010).

ii) Relief

Coastal plain, along the Sanaga River that runs through the town of Mbangassina with an altitude between 335 m and 397 m. This area has less accidental relief with a succession of hills and plateaus that are sedimentary valleys, with point of culminating the Mount Tama (882 m) above sea level (Commune de Mbangassina, 2010).

iii) Hydrography

The drainage system of the Mbangassina community is dense and permanent. The main rivers that are found in the community are: River Sanaga and River Mbam and Djim. Only River Mbam and Djim cross the Talba village. Besides these rivers, there are many streams and rivers that are tributaries. Sanaga is the longest river in Cameroon (918 km), and it is dotted with waterfalls, the most famous are those of Nachtigal to Batchenga. All these rivers are full of fish, and also a nest of black flies, which causes onchocerciasis (Commune de Mbangassina, 2010).

iv) Soil and flora

Soils in this area are ferralitic, sandy loam or lateritic in some places, rich in organic material suitable for diversified agriculture. Mining is focused on the excavation of sand, stones and laterite (Commune de Mbangassina, 2010). Sufficiently drained by numerous rivers, and also located in an area straddling the savannah and forest, the Mbangassina area has varied vegetation which consists of secondary equatorial forest, bushland and even steppe. Talba forest has greatly impoverished because of the combined effects of industrial logging, artisanal cut and slash and burn effects. Wood species often found in this forest are *Milicia excelsa* and *Terminalia superba* and *Triplochyton scleroxylon*. Furthermore it can be noted that the flora of Mbangassina is rich in non-timber forest products such as mushrooms, vines, Gnetum, Djansang, colanuts, medicinal plants, wild mangoes, rattan, bamboo, wild fruits (Commune de Mbangassina, 2010).

v) Wildlife

The fauna of this region is very diverse and abundant. It consists mainly of mammals (monkeys, deer, porcupine), reptiles (viper, crocodile), birds (partridges, toucan, parrot), fish (catfish, carp, tilapia), there are also in this area crustaceans and insects. Most of the capture of aquatic species is by net fishing, fishermen are mostly Malian origin, while the hunt of the mammals is mostly the work of indigenous peoples (Commune de Mbangassina, 2010).

3.1.3. Human milieu

i) Demography

The Mbangassina community has a predominantly agricultural population, estimated at about 60 000, with a density of 150 inhabitants per square kilometer. For Talba village, data on the exact population number has not been available; instead it has been estimated at 2000 households in Talba. Sociologically, three main groups, each of which is headed by a traditional chief of the second degree, make up the indigenous population of the municipality of Mbangassina namely:

- The Bonjo group
- The Kombe group
- The Tsinga group

These three groups contain together 19 chiefdoms of the third degree, that is, 18 villages and 01 quarter in the Mbangassina town. Talba village which has 3rd degree chiefdom, belong to the Bonjo group which contains a high ethnic diversity mainly of the Sanaga, Bafia, Eton, Manguissa, Nyambassa and Malien. There are two main population groups: indigenous peoples living in the area for several generations and alien populations or immigrants who recently arrived in the area after the construction of the Sanaga Bridge (Commune de Mbangassina, 2010).

- **Indigenous population**

To talk about the native population of Talba, we must first locate their origin in the Mbam people and in the peoples of the South Cameroon. In his analysis of settlement in Southern Cameroon, Idelette Dugast (1949) divided the people in some subgroups: Pygmy, Duala group, Bakundu, Bakoko and Bassa, the Bantu from the center, Beti and Pahouins, maka and kozime, then population with semi-Bantu language, Sudan-Bantu populations and finally Sudan. Many of these groups are found in the Mbam region, in this case three of them:

- the group named "Bantu of Centre which consists of the following ethnic groups: Banen, Nyokon, Yambetta, Lemandé, Yambassa, Bafia, Bape, Balom and Djanti;
- the group of Sudan represented by the only ethnic group Badutè;
- the group of Beti represented by Ossananga (Dugast, 1949).

Ossananga also called sanaga is one of the native to the town of Mbangassina, and found in Talba village are all three clans (Tsinga, Bonjo, Kombé) originating from this community, four other clans of the same ethnic group as scattered in neighboring municipalities namely: (Ngorro, Baveuk, Mvellé, Batsenga).

- **Alien population**

To the indigenous peoples of this area, gradually added many immigrants; including the Eton and Manguissa who were the pioneers. In 1965, neighbors like Eton and Manguissa from Lékié began to cross the Sanaga in search of agricultural land (Elong, 2004). It was only after the construction of the bridge over the Sanaga in 1979 and by a movement of migration encouraged by the government called “Operation 1,000 Families” a massive migration actually occurred favoring the settlement of people from neighboring municipalities and neighboring divisions (Elong, 2004).

ii) Socioeconomic status

- **Education and school infrastructure**

The Mbangassina community has seven secondary schools with one being run by the Catholic, while Talba village hosts two colleges being run by Catholic missionaries, including the Brother Christian Schools (Lasallians Brothers), who also direct the Rural Centre of Development of Talba (CRDT), which is a school for agricultural vocation. The village also has two kindergartens schools in Iyamboni and Talba center. In terms of infrastructure and equipment, there are insufficient graded rooms and furniture in most schools (Commune de Mbangassina, 2010).

- **Health and health infrastructure**

Coordinated by the District Health Service NTUI, health coverage of the population of this locality is provided by five health centers. There is no pharmacy, no mutuary or unit of care for AIDS patients in Mbangassina. Besides the age and degrade of local health facilities, we can also point out the destitution of their technical platform. These health centers also lack ambulances to evacuate seriously ill patients and basic medical necessities (Commune de Mbangassina, 2010).

- **Transport and road infrastructure**.

The Mbangassina community benefits from an internal road network with a length of more than 600 km of which 500 km is at the charge of the council and 100km of county roads, the rest consisting of forest and cocoa field tracks. All networks are completely none asphalted, partially degraded by of erosions and absence regular maintenance. Transportation of people and goods is ensured by individuals via motorcycles or bush taxis (Commune de Mbangassina, 2010).

- **Telecommunication and infrastructure**

This region is covered in some places by the networks of the two main private operators of mobile telephone in Cameroon namely; MTN and Orange. The different channels of national and international radio stations are received by people, although may have poor sound quality. About television, CRTV and Canal 2 are captured in some areas. However, due to lack of public secretarial or media center, it is still impossible for people to gain computer training, office work or access to Information Technologies and Communication (ITC) including the Internet (Commune de Mbangassina, 2010).

3.2. METHODOLOGY

In order to have a clear idea of previous studies that were conducted in the field of cocoa agroforestry system, information was collected through existing literature. This information was retrieved from the library of the University of Dschang, CIRAD, and IRAD Nkolbisson as well as online. Primary data collection was done in two stages: first by a socio-economic survey questionnaire (structured), and then by carrying out plot sampling. This second phase of data collection was performed using a good number of equipments (Table 2).

Table 2: Description of equipment used for data collection

Item/ Tool	**Use**
A GPS gadget	Geographical location of plot
Electronic balance	Weighing of cocoa pods and beans
A 5m ruler	Measurement of cocoa tree height
A calliper	Measurement of the diameter of cocoa trees
A machete	For opening pathways
A coloring bomb	For marking trees
Hard plastic tickets	For numbering of cocoa trees
Colrings (handcuffs)	For fixing of tickets on cocoa trees
Bold marker	For numbering tickets
5m and 30m tapes,	To demarcate the boundaries of the plot
Ribbons or band (red and white colour)	To trace the boundary of plot
Hand Tally (counter)	For counting of cocoa pods
Oil paint (Red, Blue, White, Black)	For marking of cocoa pods
Diluents	For dilution of paint
Small bucket	For carrying paint
Stick (1m to 4m)	For pod counting
Foam	Attached to one end of the stick
Ropes (rubber)	For tying foam to the stick.

3.2.1. Selection of study field

3.2.1.1. Choice of farms

The selection of farms was done thought a socio-economic survey questionnaire. In order to have reliable data on the potential cocoa yield in Talba, we stratified agroforestry systems in this village based on their levels of assumed complexity (monoculture, simplified complex), and the level of maturity of the plantations (age groups). The different levels of complexity have been defined from the following (Table 3) visual criteria.

Table 3: Description of the level of complexity of cocoa farms

Level of complexity	Characteristics
Low complexity (monoculture or full sun)	Cocoa plantation where companion trees exist very scattered or non-existent.
Intermediate level of complexity (simplified)	Associations of a small number of components, usually not more than five tree species and an annual species.
High level of complexity (complex)	Multi-strata systems, dominated land use systems with two or more strata of trees or shrubs and a substantial degree of structural complexity within at least one of the strata with high number of components.

The selection criteria of cocoa farms were done with respect to those defined by Jagoret, (2011). These selection criteria of cocoa farmers and prioritization were as follows:

- Having at least one cocoa farm, and be voluntary or show interest in research;
- The distance from the village center to the farm not exceeding 30 minutes travelling by motorbike;
- farms having an area for placing the sample plot without difficulty;
- Plantations that are not abandoned.

This study was carried out in 55 different farms with 15 having simple structure, 25 farms having complex structure, and with 15 monoculture (full sun) cocoa farms (see Table 4).

Table 4: Study farms in function of age and agroforestry systems.

Farm System	Farm age (years)				
	≤ 10	11 - 20	21 - 40	41 - 60	≥ 60
Monoculture Cocoa	5	5	5	-	-
Simple Structure	5	5	5	-	-
Complex Structure	5	5	5	5	5

3.2.1.2. Realization of study plot

In this study a rectangular plot of 800 m² (40 m × 20 m) was selected in each farm. The rectangular plot was chosen because it tends to include more heterogeneous area, so for this purpose, the sample is more representative than plots of square or circular shape of the same size (Hairiah *et al.*, 2011).

This process began by making a vivid survey around all or all almost the entire farm to have a general view of the farm in order to position the plot where it is more representative of the farm. The realization of rectangular plot itself starts by positioning two stakes 40 m apart, then the direction of the angles formed by the squares, put the other two stakes 20 m away from first two still 40 m apart in order to get the rectangular plot. After this, the plot edge trees are marked with a strong blue adhesive tape, the entire is delimited with a ribbon (red and white color, see Annex 3) and all cocoa trees on the plot marked with a coloring bomb. Each farm is numbered from 1 to 55 and the number of each farm written on a more visible tree in the farm.

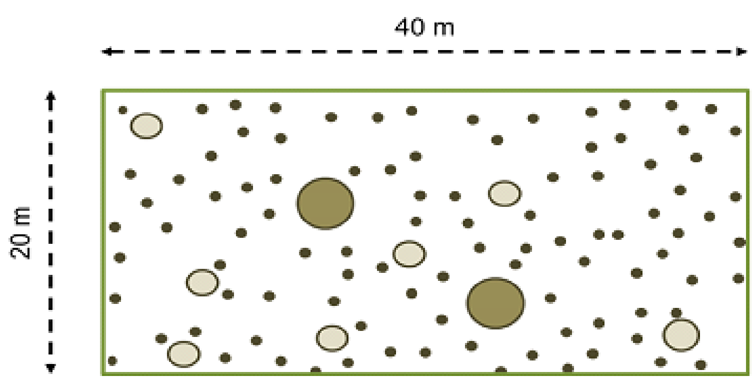

Figure 2: Rectangular plot (Saj, 2014)

3.2.1.3. Selection of cocoa trees in plot

This exercise consisted to select 16 mature cocoa trees in the plot. To achieve this, the plot width was divided with a tape or ribbon into three blocks (5 m, 10 m, and 5 m). That is, 5 m was measured from the edge of the plot in the 20 m line, afterward; eight cocoa trees (1 - 8) were selected from this distance (5 m) within the plot moving in the 40 m line. A 5 m measurement was again taken in the other opposite extreme end from the edge of the plot still in the 20 m line, now moving within the plot in the 5 m from the edge in the 40 m line, another 8 cocoa trees (9 – 16) were selected. 16 mature cocoa trees were selected at random in the 5 m line not more than 1m apart from the line as show in figure below. The selected trees are numbered from 1 to 16; 8 (1 to 8) in the ascending 5 m line and 8 (9 to 16) in the descending 5 m line. The numbering was done with a hard plastic ticket which was then attached to the tree with the use of colrings (see Annex 4). Illustration of 16 cocoa trees is shown in Figure 3.

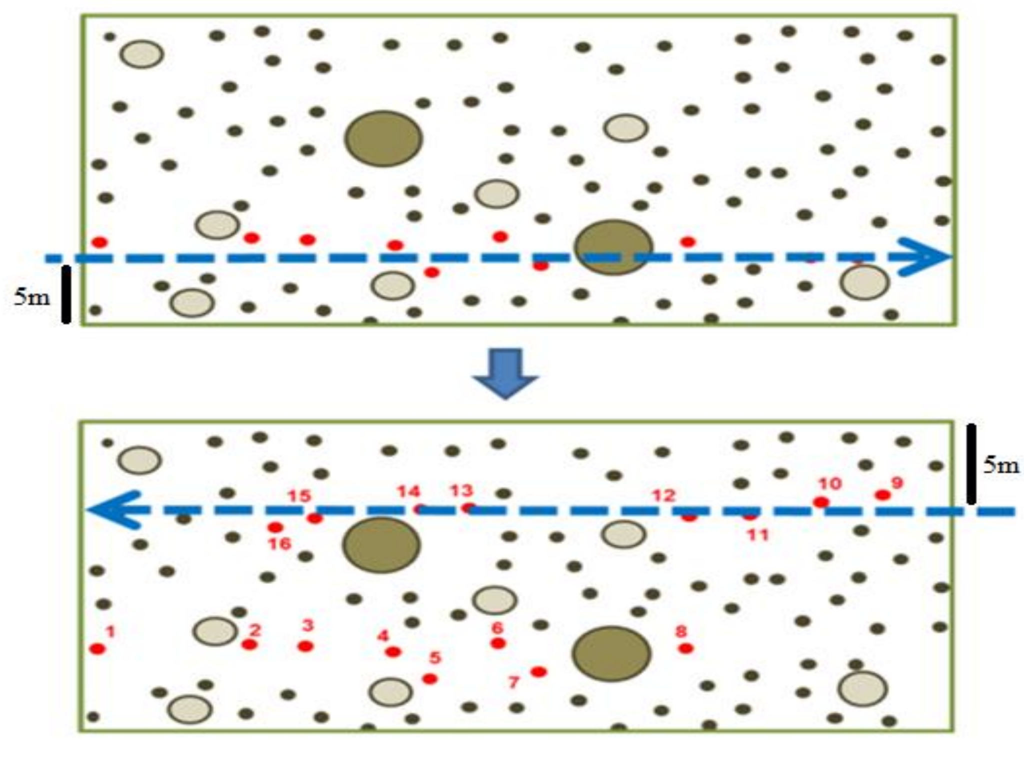

Figure 3: Criteria of 16 cocoa trees selection (Saj, 2014)

3.2.2. Data collection

3.2.2.1. Determination of height, diameter and architecture of numbered cocoa trees

The height of tree was measured using a graduated 5 m ruler. This process composed of placing the ruler at the level of the ground and extending it to the level of the highest leaf. Diameters of these cocoa trees were measured at a height of 1.2m from the ground level with the use of a caliper. Architecture was determined using the typology of cocoa tree architecture as shown in Figure 4.

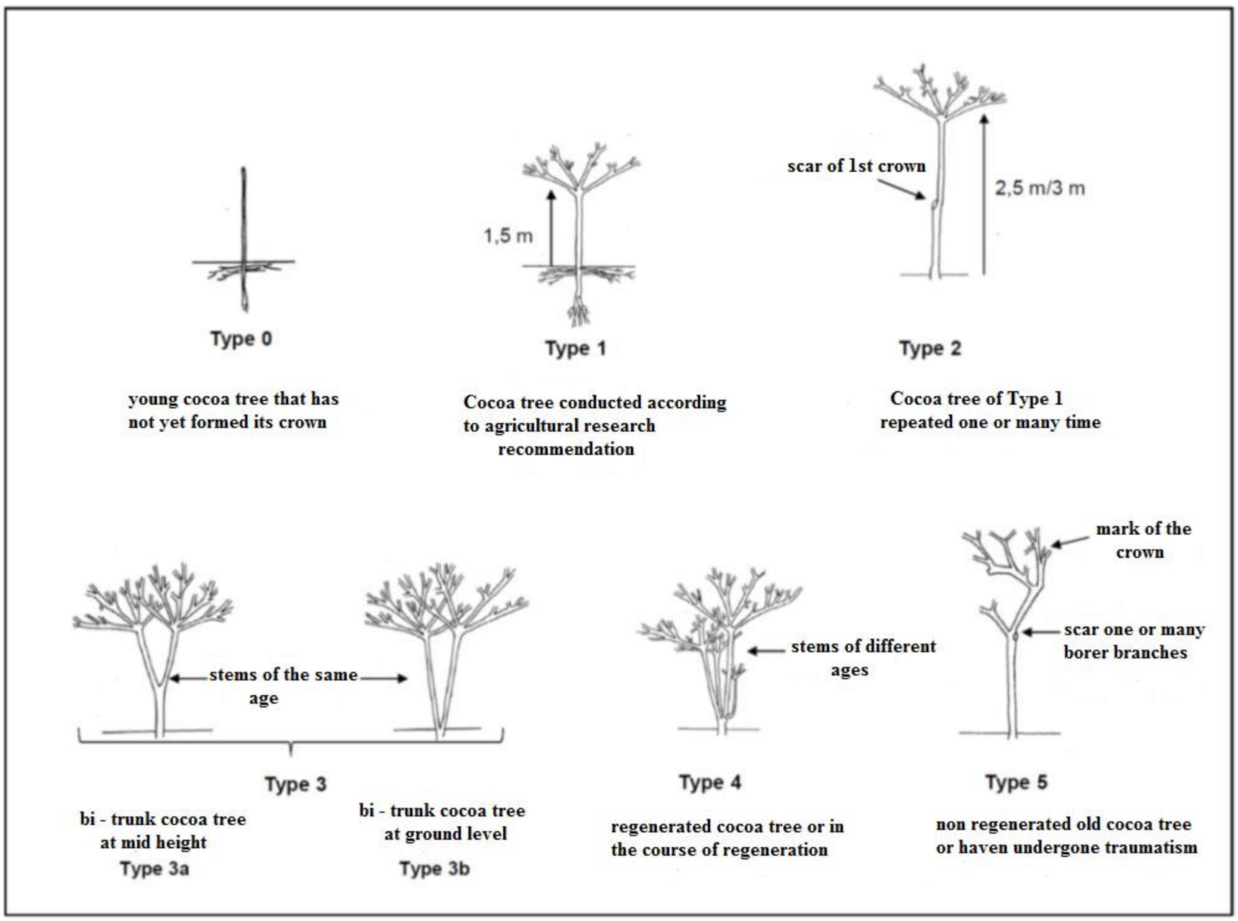

Figure 4: Typology of cocoa tree architecture (Jagoret, 2012)

3.2.2.2. Data on cocoa pods on plot

This process involved counting cocoa pods on each cocoa tree within the plot of each farm and recording the results on the data sheet. This activity was carried out four different times; in April, June, August and October 2014. Cocoa pods counted were pods >10 cm long for at this size; they were no longer too young and should not wilt. Counted pods were marked with paint so as not to be counted again in the next field survey. For each trip in a farm, the plot was first delimited with the ribbon to reduce error of forgetting some cocoa trees in the plot. This activity proper consisted of soaking foam tied to a stick in paint and marking cocoa pods >10 cm long while counting and the total number for each tree recorded. This was done for all trees in each plot and in each of the farms.

In the first field trip, red paint was used to mark mature cocoa pods, blue paint in the second trip, white paint in the third trip and black paint in the fourth trip. The same process was repeated for all the field trips but from the second trip, any cocoa pod already bearing paint mark of the previous trip was no longer counter (see Annex 5). An interval of two months was given between the field trips to allow the development of new cocoa pods taking an average of twelve (12) days to complete this activity for all the 55 study farms, giving an average of about 5 farms per day. For numbered cocoa trees in the plot, all mature cocoa pods were counted, but extra information on number of ripe pod; ripe and rotten pods; ripe and eaten pods by rodents were also taken down. The pattern of passage from one farm to the next was maintained for the different trips to keep at most a uniform interval between each farm trip.

3.2.2.3. Collection of ripe cocoa pods

Collection of cocoa pods was done in the second and fourth field trip. Two hundred cocoa pods were collected during the study period of which 100 pods in the second trip and 100 pods in the fourth trip. For each trip, 100 ripe cocoa pods were collected from 20 different farms (5 ripe pods per farm). These 20 farms were selected through paper balloting of all the 55 farms and picking 20. This process of farm selection for pod collected was repeated in the next sessions of pod collection, that is, second and fourth trip. Once the farms were selected, five ripe pods were collected from each selected irrespective of whether it is found in the plot or not. Collected pods were numerated with the farm number on the shell to avoid cases of confusion and mixing cocoa pods from different farms which will be difficult to distinguish.

3.2.2.4. Sampling of ripe cocoa pods

For each of the 200 ripe cocoa pods collected in the second and fourth trip: type of pod was determined, if it is amelonado or hybrid according to cocoa type determination (Mossu, 1990); the weight of pod; number of normal beans in pod; number of flat beans in pod; and fresh weight of normal beans. The weight of pods and fresh weight of normal beans were taken using an electronic balance (see Annex 6). Counting of normal and flat beans were done by opening the cocoa pod and removing and separating flat beans (beans that are empty) from normal beans, counting and registering the numbers on the data sheet.

3.2.3. 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:

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

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;

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

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).

3.2.4. Biomass and carbon stock

3.2.4.1. Above ground biomass

The global model used for the determination of above ground biomass in cocoa agroforestry system and forests was that of Chave *et al.* (2005). In this model we have:

AGB = 0,112 (rD2H) 0,916

With ABG = above ground biomass (kg); r = specific density of the wood (g / cm3); D = diameter at 1.3 m (cm); H = tree height (m).

The specific density r of cocoa used is 0.42 g / cm3. For each species of trees, a specific density was associated for the calculation of the above ground biomass. For species with specific densities which could not be found, we used the standard value of the specific wood density for tropical African forests which is 0.58 g / cm3 (Reyes *et al.,* 1992; IPCC, 2006).

3.2.4.2. Below ground biomass

The model that was used for the determination of the below ground biomass in cocoa agroforestry system and forests was that by COMIFAC in 2008. According to this model, we have: **BGB = AGB × R / S**

With: BGB = below ground biomass (t / ha); R / S = root / stem ratio

The R / S ratio, we used 0,235 which is recommended Mokany *et al.* (2006).

3.2.4.3. Carbon stock

The carbon stock was obtained by multiplying the amount of biomass (above and below ground) by the CF ratio (carbon fraction), which is 0.47 according to the IPCC (2006). The formula for carbon stock calculation is thus; Carbon stocks= CF x (AGB + BGB)

Where: CF = carbon fraction (0.47), AGB= above ground biomass, BGB = below ground biomass.

3.2.5. Potential yield

From data collected in the sampled plots about cocoa pods, potential yield was calculated thus;

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

Where,

Yp: potential commercial cocoa yield (kg/ha)

TNpod: total number of pods per plot

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

TC: drying coefficient (0.35)

3.2.6. Statistical analysis

Data collected from April 2014 to November 2014 were initially registered in a Microsoft Excel 2007 spreadsheet and the grouped data were imported into SPSS 21.0 version(IBM) and XLSTAT version 2014 5.02 (Addinsoft) for analysis. The effect of yield was compared through the analysis of variance (ANOVA) after data transformation to log (x + 1) followed by Tukey, Student-Newman-Keuls test for homogeonity subsets and separation of means and a P value <0.05 was considered statistically signficant. The data of each effect was grouped into plot age and system of plot. Further, the relationship between potential yield, age of farm, system/structure, basal area and mean height is investigated using an overlay in principal component analysis (PCA) graph with agroforestry system of farm and age class as supplementary variables to see the relative position these factors have in the PCA.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. POTENTIAL YIELD AND OTHER VARIABLES

On the sampled 55 plots in Talba, the average number of pods per cocoa tree was 26.9 pods. From the sampled 200 pods, the average weight of pods is 517 g with an average number of normal beans per pod being 41.7 and average weight of normal beans seeds per pod being 125.7 g. The highest number of pods on a cocoa tree for one trip count was 182 pods, this tree was found in plot with age class 20 < age ≤ 40 under full sun. In Talba, with average tree density of 1088 trees/ha, the average potential yield on sampled plots is 1178.5 kg/ha.

With respect to plot complexity, the highest value of potential yield was obtained under full sun being 2891.3 kg/ha and density of 1963 trees/ha, with the lowest value of potential yield being 204 kg/ha still under full sun with density of 963 trees/ha. This yield difference can be explained from the respective plot densities. Further to average potential yield per system, the simply system registered the highest average potential yield (1470.5 kg/ha) followed by the full sun (1440.6 kg/ha) and then the complex system (845.9 kg/ha) as represented in Figure 5.

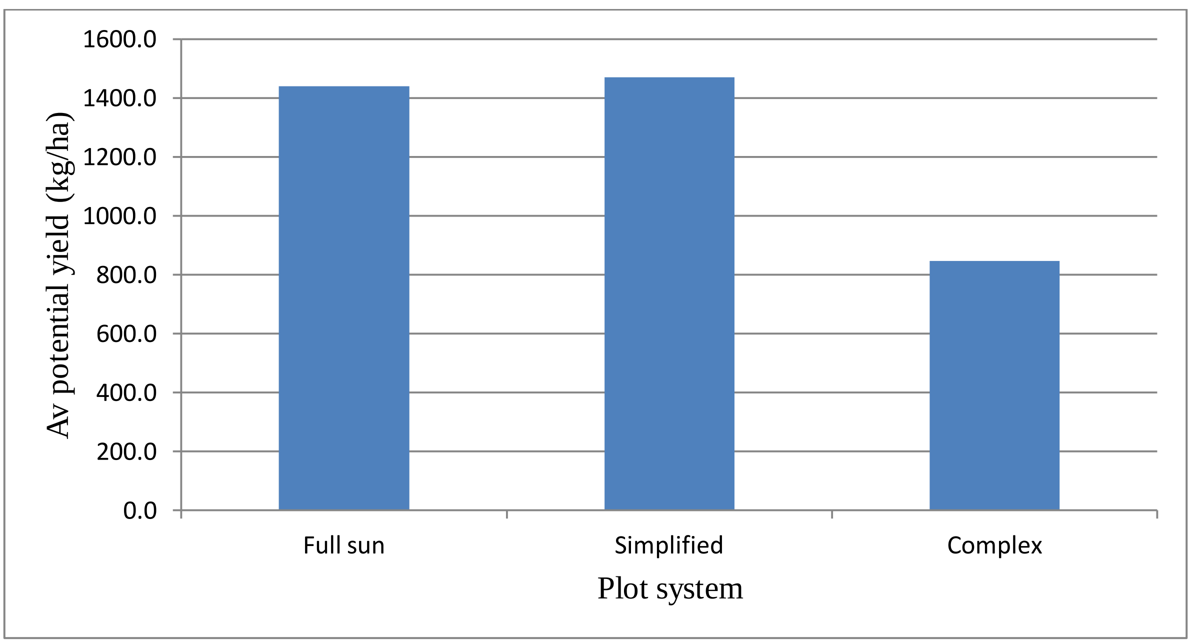

Figure 5: Potential yield with respect to plot system.

There is a significant difference of potential yield with respect to the different plot systems (F= 3.936, P= 0.027) but no significant difference of potential yield with age groups (F= 1.089, P= 0.374) tested when a two-way ANOVA was applied to the data and presented as shown in Table 5.

Table 5: Mean potential yield with respect to plot system.

System	Mean (kg/ha)
complex	845.4 ± 395.96 (a)
Full sun	1440.1 ± 419.33 (b)
simplified	1470.1 ± 419.33 (b)

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

It can be seen from Table 5 that there is a significant difference between complex system and all the other systems.

With respect to combined age class of all the three systems, the highest average potential yield was obtained in the age class of 10 < age ≤ 20 with value 1614.8 kg/ha, followed by age class of 20 < age ≤ 40 with yield value 1183.6 kg/ha, followed by age class of ≤ 10 with value 1067.1 kg/ha, followed by age class of 40 < age ≤ 60 with value 696.7 kg/ha and least age class of > 60 with value 669.9 kg/ha as represented in Figure 6.

Figure 6: Potential yield with respect to cocoa age class.

Figure 6 shows that average potential yield in Talba increases and reaches a peak at about 20 years of the cocoa field and then decreases with increasing age. Evaluating potential yield for each system, it was found that yield is highest in age class of 10 to 20 years with yield value 2127.4 kg/ha, and least at age class of ≤ 10 years with yield value 1034.7 kg/ha under full sun.

Under the simplified system, potential yield was highest in age class of ≤ 10 with value 1539.9 kg/ha and least in age class of 20 < age ≤ 40 with value 1366.2 kg/ha. In the complex system, potential yield was recorded highest in age class 10 < age ≤ 20 with value 1211.4 kg/ha and least in age class of ≤ 10 with value 626.9 kg/ha as represented in Figure 7.

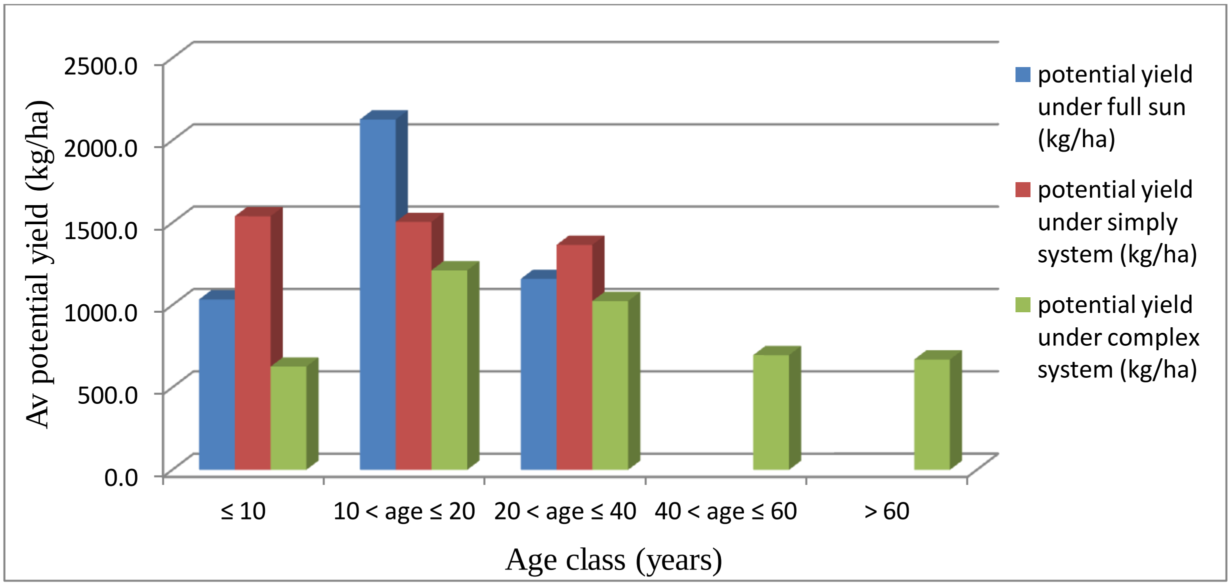

Figure 7: Potential yields under different systems with respect to cocoa plot age.

Looking at the evaluation of yield for each system separately, it shows a difference for highest yielded age class with respect to that of combined system in function of age.

The cocoa growing model in Talba appears to be very different from the one prevailing in many cocoa producing countries, such as Ivory Coast or Indonesia. In these countries, the dominant cultivation system is labour – input intensive and often favours uniform shade with little diversification (Ruf, 1995; Hanak Freud *et al*., 2000). The management strategy applied in cocoa plantations in Indonesia and Ivory Coast generates high cocoa yields in the early years (around 2–3 t/ha), but after a few years it slumps down (Petithuguenin, 1995; Lachenaud, 2005), leading to their abandonment after 30–40 years (Ruf, 1995). The cocoa stand structure in central Cameroon is therefore very different from that in other countries, such as Ivory Coast, where cocoa plantations over 40 years old account for less than 5% of cocoa stands (Hanak Freud *et al*., 2000). In central Cameroon, where 80% of cocoa plantations are over 40 years old, farmers manage to obtain cocoa yields, which though lower than for an intensive model, are maintained over a much longer time period with no fertilizer inputs. The main factors that explain the longevity of this cocoa production system include: continually replanting cocoa stands, senescent cocoa trees and the spatio-temporal management of the numerous fruit and forestry species, associated with cocoa trees of several different generations. The management of the system is also very flexible. In fact, when old cocoa plantations are taken over by a new generation of farmers, their trajectory often involves a phase of rupture followed by a revival after which the cocoa yields recover their former level (CIRAD, 2012).

In Talba, the average potential yield obtained is higher than that obtained by Jagoret (2011) on average in Bokito, Zima and Ngomedzap in the Centre region of Cameroon and that of Kazianga and Masters (2006). The latter reported that yields varied between 400 and 900 kg/ha depending on whether they are from laxly managed traditional plantations to well managed hybrid plantations. This difference in results can be explained by the fact that there has been an improvement in management practice and treatment of farms due to mobilization of farmers with respect to high quality and high yield cocoa need in Cameroon. The average potential yield obtained in a complex agroforestry system in Talba is far higher than that obtained in Costa Rica by Deheuvels *et al.* (2012). This might be judged from the difference in pedo-climatic factors of these zones. At the same time, yields from old cocoa agroforests in Talba is higher than obtained by Duguna *et al.* (2001) in forest areas in Central and Southern Cameroon, i.e. a 264–500 kg/ha depending on the intensification level.

4.2. COCOA BOTANICAL COMPOSITION AND VEGETATION STRUCTURE

4.2.1. Density

The average density of cocoa trees in Talba is 1088 plants per hectare. The density recommended by agronomic research is between 1300 and 1600 plants per hectare (Jagoret, 2012). Out of the 55 sampled plots in Talba, only 13 of these plots fall within the range of density recommended by agronomic research with 38 plots above the range and 4 plots above the range. Grouping the densities in to range of: < 1000; $1000 \geq$ trees < 1300; $1300 \geq$ trees ≤ 1600; $1600 >$ trees ≤ 1900 and > 1900, there is no significant difference of potential yield with respect to the different density range (F=2.508, P=0.054) as shown in Table 6.

Table 6: Average potential yield with respect to the density range of cocoa plots

Density range (trees/ha)	Mean potential yield (kg/ha)
< 1000	972.5 ± 425 (abc)
1000 ≥ trees < 1300	1151.7 ± 525.8 (ab)
1300 ≥ trees ≤ 1600	1366.5 ± 262.35 (ca)
1600 > trees ≤ 1900	1592.5 ± 287.1 (ac)
> 1900	2201.4 ± 191.1 (ac)

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

This can be seen in the figure 8.

Figure 8: Potential yield with respect to different plot density range.

Figure 8 shows that potential yield in Talba increase with increase in density. This can be explained by the fact that with increase number of cocoa trees, there is increase in number of pods per plot which then gives higher yield than in fewer cocoa stands. Here, the highest potential yield was recorded in cocoa plot with density > 1900 trees/ha with value of 2201.4 kg/ha and the lowest registered in cocoa plot with density < 1000 trees/ha. Cocoa plots within the density range recommended by agricultural research (1300 to 1600 trees/ha) recorded a potential yield value of 1366.5 kg/ha. According to Sonwa (2004), where pesticides are not applied, high density of cocoa do not provide more cocoa beans production. This information is contrary to what is observed in Talba where the number of developed pods increased with density.

Evaluating plot density with respect to age class and system, cocoa densities proved to be significantly different with respect to age class (F=8.039, P=0.000), also a significant difference was observed between cocoa densities with respect to the plot system (F=3.75, P=0.030) as seen in Table 7.

Table 7: Mean cocoa density of plot with respect to age class and system of the plot.

Age	**Mean density(ind/ha)**
≤ 10	1356.67 ± 355.22 (a)
10 < age ≤ 20	1239.17 ± 310.59 (ac)
20 < age ≤ 40	866.67 ± 813 (bc)
40 < age ≤ 60	715 ± 266.4 (bc)
> 60	870 ± 392.87 (bc)
System	
Full sun	1129.17 ± 354.43 (a)
Simplified	1273.33 ± 403.97 (ac)
Complex	953 ± 345.46 (ac)

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

The graphical representation of density with respect to age class can show as in Figure 9.

Figure 9: Average cocoa density with respect to different plot age groups.

It is shown from Figure 9 that average density in Talba reduces with increase in age right to age group 40 years to 60 years and increases in age group greater than 60 years. This can be explained by the fact that as the plantation gets old, some cocoa trees die due to disease attack or cut off if not productive and after the age of 40 where there is a great decline in density, these dead plants are replaced, so therefore at age greater than 60, there is increase in density due to the replacement. Representation of cocoa density with respect to plot system can be seen in Figure 10.

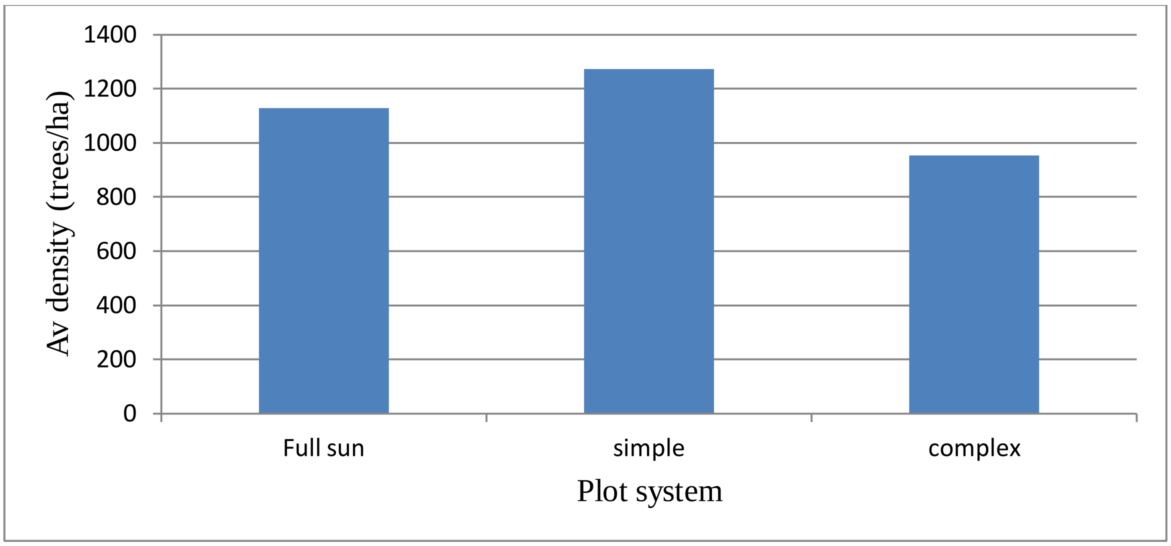

Figure 10: Average cocoa density with respect to different plot systems

Evaluating density with respect to system, it has been shown that the highest density is found in a simple system (1273 trees/ha) followed by full sun (1129 trees/ha) with the least density in a complex system (953 trees/ha). This can be justified by the fact that in full sun, plants are in total exposure to sunlight and tend to produce much expanded branches and therefore highly spaced out contrary to a simple system where cocoa trees are under shade and tend instead to grow taller and therefore leaving space for more plants to be added. Meanwhile in a complex system, there is high density of associated trees compared to that in a simple system and this explains the density decrease in a complex system. This is case of Talba and is not a general case as it may be found contrary in some other areas or zones.

4.2.2. Basal area

The average basal area gotten per hectare is 28.8 m^2/ha. Grouping the various plot cocoa basal area into categories of less than 10, 10 to 20, 20 to 30, 30 to 40 and greater than 40, the category 30 to 40 gave the highest potential yield figure (1501.28 kg/ha). There is a significant difference of yield with respect to the different cocoa basal area categories (F=5.786, P=0.001) as shown in Table 8.

Table 8: Average basal area with respect to age of cocoa farms

Basal area category (m^2/ha)	Mean potential yield (kg/ha)
< 10	376.28 ± 127.29 (ac)
10 ≥ ba < 20	676.62 ± 316.95 (ac)
20 ≥ ba < 30	1137.67 ± 642.18 (ac)
30 ≥ ba < 40	1501.29 ± 568.23 (bc)
≥ 40	1400.9 ± 689.24 (bc)

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

This can be represented as shown in Figure 11.

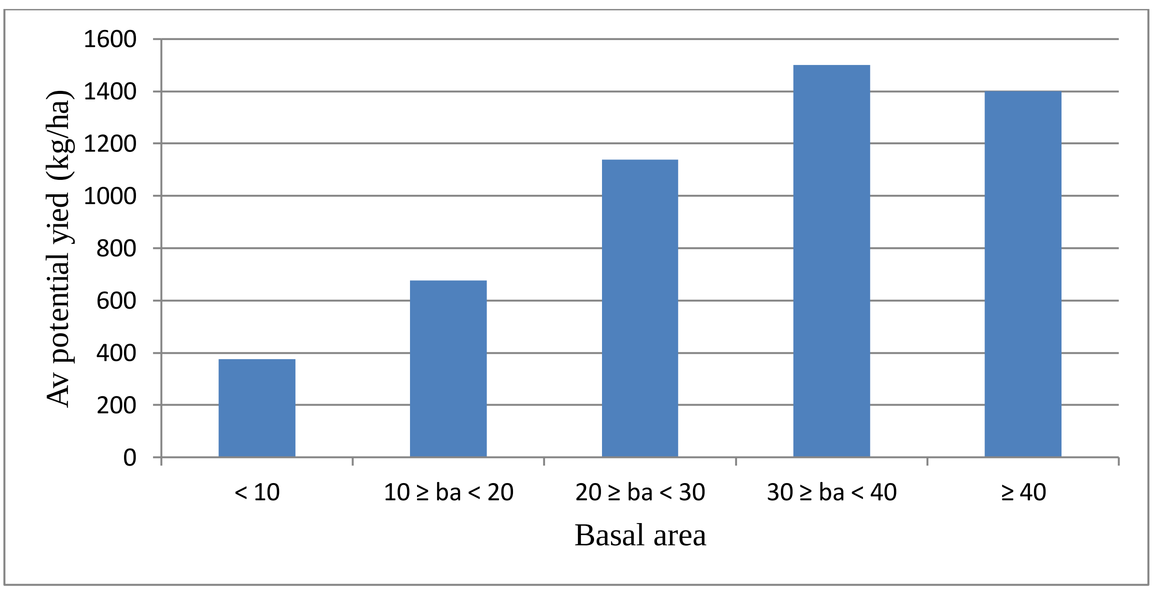

Figure 11: Potential with respect to different basal area groups of cocoa plots.

It can be seen from Figure 11 that cocoa yield increases with increase in cocoa tree basal area which is confirmation with CIRAD (2012) which says 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.

Evaluating age and stand basal area of cocoa, there is a significant difference of cocoa stand basal area with respect to the different cocoa age class (F=5.750, P=0.001) as shown in Table 9.

Table 9: Average basal area with respect to age of cocoa farms

Age	Basal area (m^2/ha)
≤ 10	18.5 ± 13.9 (ac)
10 < age ≤ 20	30.9 ± 6.9 (bc)
20 < age ≤ 40	33.5 ± 8.2 (bc)
40 < age ≤ 60	28.01 ± 13.7 (abc)
> 60	40.4 ± 12.9 (bc)

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

As a cocoa tree grows older, its basal area increases (Figure 12), thereby creating enough space for development of cocoa pods on the tree.

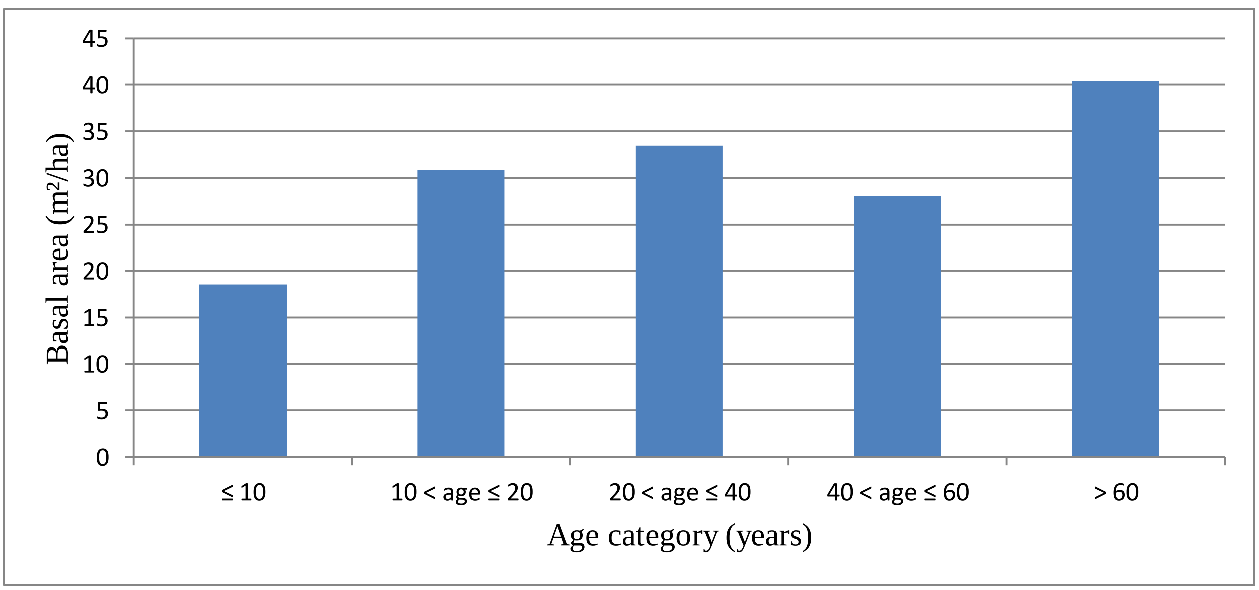

Figure 12: Cocoa basal area with respect to different plot age groups.

Increased basal area accounts for the increase of cocoa yield with increase in cocoa field age and has a good link with 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 more stems on a tree, the more pods will be developed on that cocoa tree. This holds true with findings from CIRAD (2012) that there is a 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.

The basal area is the cross sectional area of the stem or stems of a plant or of all plants in a stand, generally expressed in square units per unit area. In plantation forestry, a fairly good correlation exists within species between the basal area of a tree and the cross sectional area of its crown, and the sum of all basal areas in a stand (stand basal area) has 35 units conventionally served as basis for the scheduling of thinning to reduce inter-tree competition (Smith *et al.*, 1997; Sonwa and Weise, 2008). The basal area is also recognized to be useful for monitoring of agroforestry systems, where crops and trees are mixed (Nissen *et al.*, 2002; Sonwa and Weise, 2008). Studies by Sonwa (2004), taking into consideration cocoa and associated plants, obtained an average basal area of 36 m²/ha on which 85% are taken up by the plants associated with cocoa. This study conducted in different ecological zones and different types of cocoa plantations gave the average of 30 m²/ha for plants associated with cocoa. There was no statistical difference between ecological region and type of cocoa for better achievement of a multistrata system (Sonwa and Weise, 2008).

4.2.3. Cocoa carbon stocks and biomass

Average cocoa carbon stocks in Talba is 8.75 t/ha and average biomass of 19.26 t/ha with highest registered carbon stocks and biomass in the age group of > 60 with values of 13.042 t/ha and 27.952 t/ha respectively; and lowest in age group of < 10 with values of 5.3 t/ha and 6.8 t/ha respectively. In this zone, there is a significant difference in cocoa carbon stocks with respect to age of cocoa plot (F= 5.946, P= 0.001), as well, there is significant difference in biomass with respect to age of cocoa plot (F=16.243, 0,000) as seen in Table 10.

Table 10: Mean cocoa dry biomass and carbon stocks with respect to age of cocoa plots.

Biomass	
Age class	Mean (t/ha)
≤ 10	6.8 ± 3.2 (a)
10 < age ≤ 20	11.7 ± 2.9 (c)
20 < age ≤ 40	15.4 ± 6.4 (b)
40 < age ≤ 60	21.1 ± 7.95 (bc)
> 60	23.6 ± 6.0 (b)
Carbon stocks	
Age class	Mean (t/ha)
≤ 10	5.3 ± 4.4 (a)
10 < age ≤ 20	9.0 ± 2.5 (b)
20 < age ≤ 40	10.2 ± 2.9 (b)
40 < age ≤ 60	9.5 ± 4.7 (ab)
> 60	13.0 ± 4.5 (b)

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

This can be represented as in Figure 13.

Figure 13: Biomass and carbon stocks with respect to different plot age groups.

Cocoa carbon stocks and biomass increases with age of cocoa field which agrees with that of Somarriba *et al.* (2013) who observed that the annual rate of accumulation of carbon in aboveground biomass varied with plantation age in Central America. Saj *et al.* (2013) found live tree carbon storage did not increase significantly with plantation age. Hence, despite a regular increase of their carbon content, cocoa trees did not significantly contribute to carbon storage when aging, and found on average in Centre Cameroon total carbon 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 carbon.

Forests are the main atmospheric carbon dioxide sink on Earth. The carbon stock of the local climax forest depends on the ecological conditions (rainfall, temperature, soil, local flora and fauna) that determine tree growth. The transformation of primary forests into cocoa plantations entails a drastic reduction of forest carbon to give room and create light and air circulation conditions adequate for cocoa production. In Central and West Africa, the conversion of natural forests into cocoa plantations resulted in a 50% loss of biomass (Duguma *et al*., 2001). In Cameroon, out of the original forest's 204 mg C ha−1 stored in aboveground biomass, rustic cocoa plantation retained 126 mg C ha−1, that is, 38% of the forest carbon was lost (Kotto-Same *et al*., 1997; Somarriba *et al*., 2013). Moreover, it seems that carbon storage dynamics of companions may be fast after plantation (8 years) and then maintained at a certain level depending either on local pedoclimatic conditions and/or farmers management (clearing and pruning for instance). Cocoa share in carbon stock remains low and represents on average 10 % of total carbon stock in live trees, despite cocoa trees being at least 10 times more numerous than companions. Unexpectedly, total carbon storage in live trees did not differ between sites, previous systems or plantation ages and appeared relatively independent from some categories of live (Saj *et al*., 2013). If recommend structural changes and management practices to promote both complexity and carbon storage while maintaining cocoa production potential, the study of this short number of systems may help to select and test factors that would be promising for both conservation and carbon storage. We can therefore conclude from this that cocoa trees do not store much carbon as compared to other forest trees.

4.3. COCOA YIELD RELATIONSHIP WITH OTHER YIELD FACTORS

For cocoa yield relationship with other yield factors, variables were observed with Pearson at 0.05 for their correlation and the relationship of cocoa potential yield with other field factors was elaborated on a principal component analysis (PCA) as shown in Figure 14.

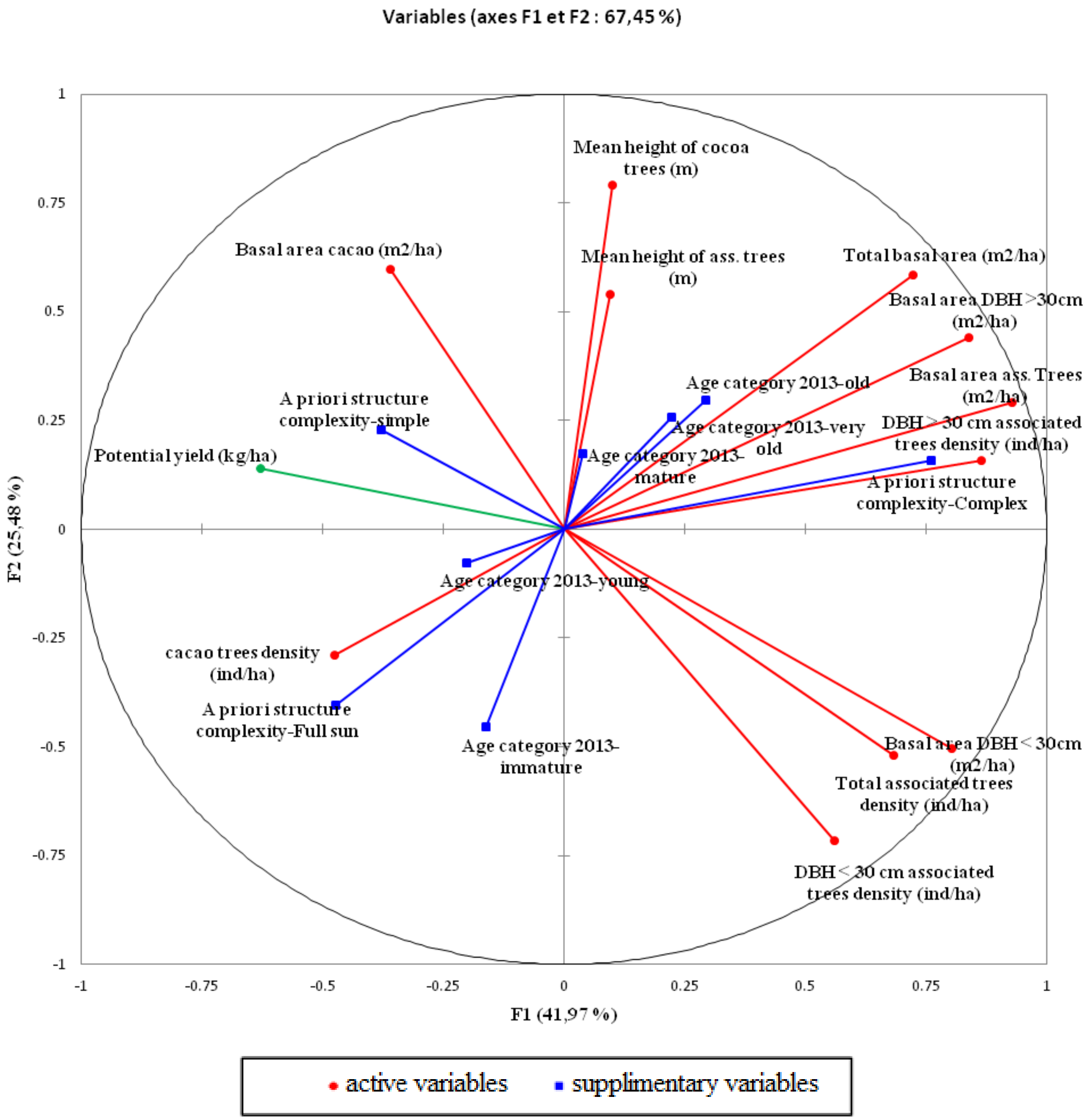

Figure 14: Principal Component Analysis (PCA).

On the PCA, the F1 and F2 axis represent 67.45% of the information. Active variables here include; cocoa tree density, basal area of cocoa and associated trees, diameter at breast height (DBH), associated tree density, mean height of cocoa and associated trees. And we have as supplementary variables age category and structure complexity. From the illustration above, the main variable is potential yield and the closer any active variable is to the main factor, shows how closely related that variable is to potential yield of cocoa. It can be seen from the PCA that cocoa basal and cocoa tree density are closely related to cocoa potential yield.

It can be seen from the correlation table in Annex 9 that potential yields increases significantly with cocoa basal area and cocoa tree density and has poor correlation with mean height of cocoa tree. Cocoa potential yield shows a negative correlation with basal area of associated trees, diameter at breast height of associated trees and density of associated trees. Cocoa basal area shows a strong positive correlation with mean height of cocoa tree and a weak positive correlation with cocoa tree density.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

Yield evaluation in Talba showed a positive effect of shade in a simple system on potential yield as compared to that of a complex system. This results obtained is higher than that obtained in the full sun system and this therefore approves the high cocoa yield and biodiversity conservation of the simple system agroforestry cocoa plot, hence sustainable. Differential management of shade tree species in different farms, aimed at providing good growth and yield conditions (microclimatic) for both cocoa and timber, has resulted to difference in yield with respect to shade intensity. With respect to associated tree management in Talba, there is high preference for fruit trees like citrus fruits, plum and cola plant due to the good prices on the local markets. But farmers generally do not put it on top priority for cola plant association with cocoa for according to them, cola plants are also attacked by mirids which are the principal pests of cocoa.

This study on evaluation of yield has permitted the situation of the level of the yields in Talba cocoa agro-forests. This study has help throw more light on the functioning of complex cocoa agro-forests in the Talba and the Centre region of Cameroon at large. Analysis of the components of the cocoa agro-forests in Talba has brought out non investigated relationships between potential yields and all other factors on which it depends. 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. Also revealed is the diverse management strategies adopted by farmers in managing their family agro-forests. Shade should be maintained at about 70% in the first 10 years of the plants life and reduced to about 50% after but the problem that arises is how to determine that percentage of shade has been attained. The potential yield doesn’t vary considerably with the different age classes of plots but at an individual level there are large variations in potential yield depending on the care each farmer gives his farm. In a nutshell, cocoa yield greatly depends on the farm system, cocoa tree structure and field density.

5.2. RECOMMENDATIONS

5.2.1. Research Institutions and Universities

It would be of great interest to initiate and implement a digital database in which the names and plant species (woody and herbaceous) encountered in the field by the trainees and other related research works, make it more effective and credible the results of research by multiplying advantage of the experimental sites within the same country where cocoa is grown. And also to initiate benefit studies and research on the functioning of agroforestry systems, based on cash crops, other than coffee and cocoa in Cameroon.

5.2.2. Public Services

It is recommended to the public service to organize farmer training seminars on effective management and operation of their cocoa agroforests to better the production and quality of cocoa in Cameroon, intensify and finance research towards the optimization of cocoa yields in all traditional farming systems in different growing regions in Cameroon as well as other cash crops. They should also make a regular tour to visit some of these farmers in agroforestry plantations, to inform them of the importance of the species present in their plantations.

5.2.3. Farmers

The farmers are recommended to implement the filling of big gaps in their plantations to improve the density of cocoa per hectare where the density is very low, maintain a good practice of pruning and clearing of their farms and respect and their treatment calendars so as to reduce the incidence of pest and diseases. They should always be regular in the farm to carryout sanitary harvesting in their farms to reduce the propagation and invasion of disease like in the case of cocoa black pod disease. And finally, form an organization of farmers where information on better production can be shared or useful information from external organization or public service can easily reach them.

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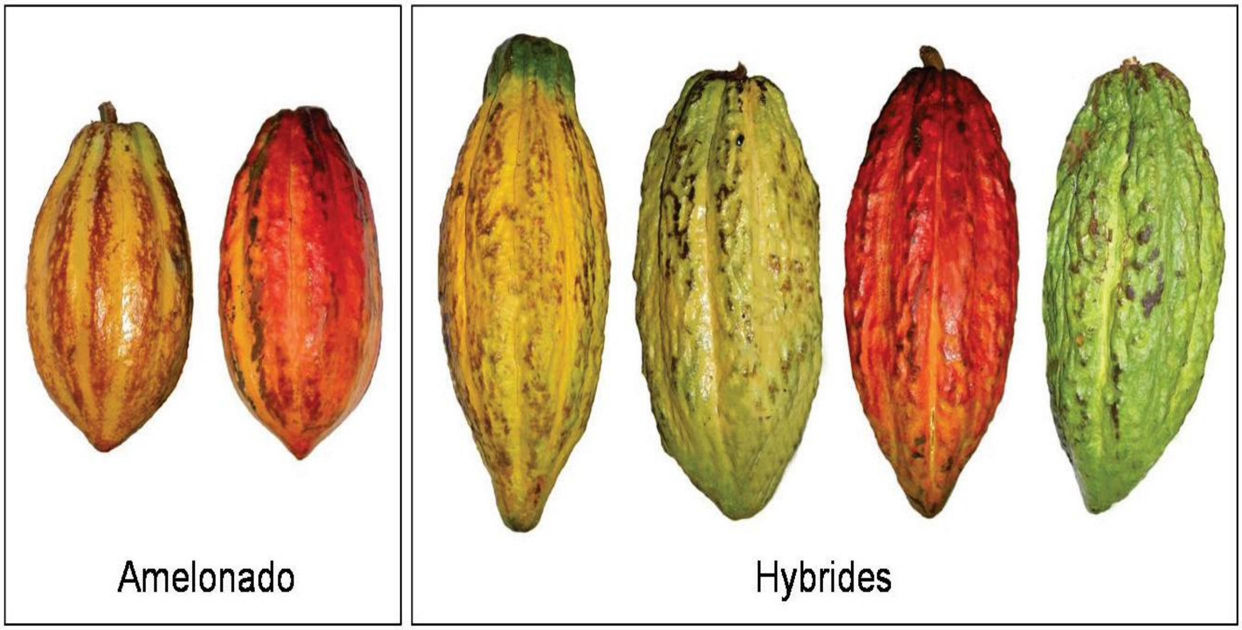
ANNEXES



Annex 1: Amelonado and hybrid cocoa (Mossu, 1990)

Annex 2: Cocoa pod attacked by black pod disease

Annex 3: Plot delimited with red and white colour ribbon and pod counting.

Annex 4: Numbered cocoa trees.

Annex 5: Counted cocoa pods

Annex 6: Weighing of cocoa pods and beans with an electronic balance.

Field n°	Nom planteur	Coordonnées GPS	N :	E :	N :	E :
5	Manengue Jean	des angles	N :	E :	N :	E :

Square size according to GPS (m²)

1 case = un comptage de cabosses sur un cacaoyer

Passage 1 / date : 23/04/2014 / peinture : Red

cocoa 1	1	cocoa 9	0	21
cocoa 2	0	cocoa 10	0	7
cocoa 3	1	cocoa 11	0	4
cocoa 4	12	cocoa 12	2	0
cocoa 5	14	cocoa 13	0	0
cocoa 6	3	cocoa 14	4	0
cocoa 7	0	cocoa 15	13	0
cocoa 8	2	cocoa 16	5	0
8	0	4	0	0
3	2	0	6	0
4	4	6	5	0
20	2	5	13	0
0	0	0	2	5
3	12	5	11	2
2	0	14	0	0
11	6	0	5	4
17	0	0	0	1
29	7	19	0	2
7	3	0	0	0
10	17	0	2	2
18	3	0	4	0
11	26	13	0	0
2	10	8	3	0
2	5	0	0	0
0	3	9	2	2
0	36	5	2	3
0	2	36	12	6
0	1	1	0	
5	2	4	0	
1	5	5	0	
7	14	7	3	
10	11	1	0	
8	5	3	3	
23	0	0	1	
6	5	0	0	
0	1	32	8	

total passage 1 =

1 case = un comptage de cabosses sur un cacaoyer

Passage 2 / date : 17/06/2014 / peinture : Blue

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

total passage 2 =

1 case = un comptage de cabosses sur un cacaoyer

Passage 3 / date : 23/08/2014 / peinture : White

cocoa 1	1	cocoa 9	6	7
cocoa 2	0	cocoa 10	1	17
cocoa 3	15	cocoa 11	12	8
cocoa 4	22	cocoa 12	16	16
cocoa 5	12	cocoa 13	3	6
cocoa 6	6	cocoa 14	3	6
cocoa 7	2	cocoa 15	8	19
cocoa 8	2	cocoa 16	5	3
26	6	9	0	8
9	0	19	23	7
10	0	14	14	18
14	11	20	0	0
4	21	37	1	17
8	3	17	6	3
18	1	23	36	15
3	0	0	0	0
14	0	1	1	5
7	12	13	5	4
15	17	0	0	11
0	20	0	0	6
5	36	5	8	0
31	5	7	5	2
2	26	6	17	2
31	3	15	0	2
0	10	19	14	6
2	9	9	14	3
52	19	7	9	4
9	9	37	7	
15	0	14	11	
12	2	18	4	
9	14	11	1	
25	15	34	6	
29	5	8	12	
7	34	2	3	
6	0	0	0	
16	5	0	0	

total passage 3 =

Annex 7: Data sheet for counted cocoa pods in plot

Field n	5				Nom planteur	Manengue												
					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	Architecture	Passage 1 peinture : Red date: 23/04/2014	Nb total de cabosses mûres	*Nb cabosses mûres saines*	*Nb cabosses mûres pourries*	Nb cabosses rongées	Passage 2 peinture : Blue date: 17/06/2014	Nb total de cabosses mûres	*Nb cabosses mûres saines*	*Nb cabosses mûres pourries*	Nb cabosses rongées	Passage 3 peinture : White date: 23/08/2014	Nb total de cabosses mûres	*Nb cabosses mûres saines*	*Nb cabosses mûres pourries*	Nb cabosses rongées
Cocoa tree 1	5.2	6	2		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 2	2.45	3.9	1		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 3	4.15	7	2		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 4	5.8	7.6	2		2	2	0	0		0	0	0	0		0	0	0	0
Cocoa tree 5	5.15	8	2		8	8	0	0		0	0	0	0		0	0	0	0
Cocoa tree 6	6.1	9.7	2		2	2	0	0		0	0	0	0		0	0	0	0
Cocoa tree 7	3.8	7.8	2		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 8	3.25	6.4	2		2	2	0	0		0	0	0	0		0	0	0	0
Cocoa tree 9	3.7	7.4	2		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 10	3.9	7	2		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 11	4.65	8.4	2		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 12	6	12.3	2		1	1	0	0		0	0	0	0		0	0	0	0
Cocoa tree 13	3.3	6.2	2		0	0	0	0		0	0	0	0		0	0	0	0
Cocoa tree 14	4.75	9	2		4	4	0	0		0	0	0	0		0	0	0	0
Cocoa tree 15	4.4	8.5	2		11	11	0	0		0	0	0	0		0	0	0	0
Cocoa tree 16	2.85	6.2	2		1	1	0	0		0	0	0	0		0	0	0	0

Annex 8: Data sheet for architecture, height, diameter of cocoa trees and cocoa ripe pods.

Matrice de corrélation (Pearson) :												
Variables	Potential yield (kg/ha)	ees density	)ciated trees	)ciated trees	ted trees der	area cacao (m	a DBH < 30cm	a DBH >30cm	ea ass. Trees	basal area (m	ight of cocoa	ight of ass. trees (m)
Potential yield (kg/ha)	1	0.444	-0.311	-0.451	-0.434	0.450	-0.402	-0.424	-0.482	-0.241	0.142	-0.145
cacao trees density (ind/ha)	0.444	1	0.010	-0.291	-0.113	0.180	-0.259	-0.417	-0.443	-0.340	-0.338	-0.230
DBH < 30 cm associated trees density (ind/ha	-0.311	0.010	1	0.299	0.918	-0.404	0.869	0.101	0.289	0.078	-0.343	-0.413
DBH > 30 cm associated trees density (ind/ha	-0.451	-0.291	0.299	1	0.653	-0.277	0.386	0.829	0.852	0.689	0.088	0.233
Total associated trees density (ind/ha)	-0.434	-0.113	0.918	0.653	1	-0.435	0.850	0.424	0.583	0.348	-0.236	-0.231
Basal area cacao (m2/ha)	0.450	0.180	-0.404	-0.277	-0.435	1	-0.364	-0.132	-0.204	0.306	0.679	-0.063
Basal area DBH < 30cm (m2/ha)	-0.402	-0.259	0.869	0.386	0.850	-0.364	1	0.233	0.441	0.245	-0.093	-0.334
Basal area DBH >30cm (m2/ha)	-0.424	-0.417	0.101	0.829	0.424	-0.132	0.233	1	0.976	0.882	0.302	0.311
Basal area ass. Trees (m2/ha)	-0.482	-0.443	0.289	0.852	0.583	-0.204	0.441	0.976	1	0.870	0.257	0.212
Total basal area (m2/ha)	-0.241	-0.340	0.078	0.689	0.348	0.306	0.245	0.882	0.870	1	0.593	0.174
Mean height of cocoa trees (m)	0.142	-0.338	-0.343	0.088	-0.236	0.679	-0.093	0.302	0.257	0.593	1	0.226
Mean height of ass. trees (m)	-0.145	-0.230	-0.413	0.233	-0.231	-0.063	-0.334	0.311	0.212	0.174	0.226	1

Les valeurs en gras sont différentes de 0 à un niveau de signification alpha=0,05

Annex 9: Pearson's correlation matrix