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Effects of management options, some ecological factors and soil fertility on cocoa yields in cocoa agro-ecosystems in the Ntui Subdivision

Dissertation

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To those who have filled my life with encouragement and love

My family

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LIST OF ABBREVIATIONS

DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization
GPS	Geographical Position System
IITA	International Institute for Tropical Agriculture
IRAD	Institute of Agricultural Research for Development
SODECAO	Société de Développement du Cacao
SOM	Soil Organic Matter
PDC	Plan de Developpement Communal

ABSTRACT

The Center Region currently produces over 40 % of cocoa in Cameroon. Serious yield gaps exist among farmers that are generally attributed to farm management, and ecological factors/soil fertility status. A study was conducted to access the relationship between certain yield factors and average cocoa yield of selected cocoa agroecosystems in the center region alongside a yield gradient from June to December 2020. Investigation of 100 cocoa farmers to capture farm management practices was carried out, 30 selected cocoa plantations were assessed for specific bio - physical characterization, soils sampled at a depth of 0 – 30 cm and cocoa leaf tissues were analyzed for selected fertility characteristics. Results revealed that, average cocoa yield in the Ntui location was 630.1 kg/ha, with a minimum value of 105 kg/ha, maximum value of 1365.3 kg/ha and coefficient of variation of 74.87 %. Pearson's correlation coefficient revealed that; estimated cocoa yields increase significantly with cocoa agroecosystem surface area (r= 0,7087; p= 0.0001) and the variety of cocoa grown (r = 0.6769; p = 0.0003) but deceases significantly with an increased with associated trees densities (r = -0.7148; p = < 0.0001), plant diversity (r = -0.7029; p = 0.0001). Also, the application of chemical fertilizer correlated significantly with cocoa agroecosystems surface area (r = -0.7514; p = < 0.0001), as well as the quantity of chemical fertilizer applied (r = -0.8128; <0.0001). Result from regression analysis indicated that, frequency of spraying insecticide against capsids, the soil fertility parameters: potassium; magnesium, the soil structural parameter sand, the cocoa leaf area index and the associates tree species densities had a significant impact on cocoa yield and were the only measured variables that remained in the final model. Hence particular attentions need to be made on these parameters as far as these parameters are concerned.

Keywords: Cocoa, agroecosystem; farm management practices, yield gap.

RESUME

La Région du Centre produit actuellement plus de 40% du cacao au Cameroun. Il existe de grands écarts de rendement entre les agriculteurs, généralement attribués au mode de gestion agricole, aux facteurs écologiques/fertilité des sols. Une étude a été menée pour établir la relation entre ces facteurs et le rendement moyen en cacao de quelque agroécosystème cacaoyers dans la région du centre parallèlement à un gradient de rendement entre la période de juin – décembre 2020. Une enquête a été menée auprès de 100 producteurs de cacao pour recenser les pratiques de gestion agricole, 30 cacaoyères sélectionnées ont été évaluées pour une caractérisation biophysique spécifique. Les sols échantillonnés à une profondeur de 0 à 30 cm et les feuilles de cacao ont été analysés pour certaines caractéristiques de fertilité. Les résultats ont révélé que le rendement moyen du cacao dans la localité de Ntui était 630,1 kg / ha, avec une valeur minimale de 105 kg / ha, une valeur maximale de 1365,3 kg / ha et un coefficient de variation de 74,87%. Le coefficient de corrélation de Pearson a révélé que ; les rendements estimés du cacao augmentent significativement avec la superficie des agroécosystèmes cacaoyer (r= 0,7087 ; p= 0,0001) et la variété de cacao cultivé (r = 0,6769 ; p = 0,0003) mais décroissent significativement avec une augmentation des densités d'arbres associées (r = - 0,7148 ; p = < 0,0001) et diversité végétale (r = -0,7029 ; p = 0,0001). De plus, l'application d'engrais chimiques était significativement corrélée à la superficie des agroécosystèmes cacaoyers (r = -0,7514 ; p = < 0,0001), ainsi qu'à la quantité d'engrais chimique appliquée (r = -0,8128 ; < 0,0001). Le résultat de l'analyse de régression a indiqué que, fréquence de pulvérisation d'insecticide contre les capsides, les paramètres de fertilité du sol : potassium ; magnésium, le paramètre structurel du sol le sable, l'indice de surface foliaire du cacaoyer et les densités d'espèces d'arbres associées ont eu un impact significatif sur le rendement en cacao et étaient les seules variables mesurées qui sont restées dans le modèle final. Par conséquent, une attention particulière doit être apportée à ces paramètres en ce qui concerne le maintien de la fertilité des sols de cette zone d'étude.

Mots Clés : Cacao, agroécosystème ; pratiques agricole, écart de rendement

CHAPTER I. GENERALITIES

I. 1. INTRODUCTION

I. 1. 1. Context and Justification of the study

The cocoa tree (*Theobroma cacao* L.) belongs to the Malvaceae family and is native to the tropical rain forests of Central and South America (Alverson *et al.*, 1999). The Germans first introduced cocoa in Africa through Ghana in 1857 and in Cameroon precisely through Victoria (Limbe) in 1886 (Voula *et al.*, 2018). The nutritional and pharmaceutical importance of cocoa makes it one of the main export products for certain tropical countries.

Cocoa farming is an extremely labor-intensive form of agriculture, concentrated in some of the lowest income earners countries in the world. In the humid tropics, cocoa is grown in a multispecies system that have many potential advantages that could be tapped depending on the relationships and regulations between species in the agroecosystem, i.e., a higher overall productivity per unit area, a better control of pest pressure, and increased environmental services such as biodiversity conservation, soil fertility, and carbon sequestration (Malézieux *et al*., 2008; Jagoret *et al*., 2017; Adeniyi *et al*., 2019). The complexity of such agroecosystems and the different objectives they address make it hard to evaluate their productivity and identify factors limiting yields of the main crop (Malézieux *et al*., 2008).

Cocoa agroecosystems are of particular interest in this setting. World cocoa production reached 4,849 million tons for the 2018 – 2019 cocoa growing seasons and with an annual production estimated at 264,000 tons during the above-mentioned cocoa growing season, Cameroon did not still meet up with the government set target of 600 000 tons annually for 2020 (Voula *et al*., 2018). Meanwhile, the global cocoa orchard covers 10 million ha of land and it is characterized by yield differences between plantations, ranging from 80 to 4000 kg per ha, depending on farmers' practices and cropping systems (Rafflegeau *et al*., 2014; Jagoret *et al*., 2017).

Cocoa cropping is generally based on two different approaches: (i) an intensive model that promotes the use of selected varieties managed without shade or under homogeneous light shade, with high chemical fertilizer and pesticide inputs (Wood and Lass, 2001), and (ii) agroforestry systems which represent 50 to 60 % of the world cocoa orchard and where cocoa trees are associated with other multipurpose forest or fruit trees (Clough *et al*., 2009). The associated trees provide shade to the cocoa trees, and many products to farmers (fruit, wood, leaves, medicinal barks, etc.), whether marketed or not, which contribute to the self-sufficiency and the economic equilibrium of the households (Cerda *et al*., 2014; Jagoret *et al*., 2014a). Although the intensive model has reached it limits in term of sustainability, a real tradeoff has not really been established as far as the functioning of these complex cocoa agroecosystems is concerned (Jagoret *et al.*, 2017). This is principally due to three (03) reasons; (i) based on the assumption that shade limits productivity of cocoa trees, researchers overlooked cocoa agroecosystems due to their presumed low yields, (ii) all benchmarks studies of cocoa agroecosystems were carried out based on – stations trials conducted over 1950 – 1980 periods and (iii) assessing the specific yield of a given species in these systems is hard because it involves taking explicitly into account the other cultivated species in the system, their place, and role (Malézieux *et al*., 2008).

This is also the case of Central Cameroon, where, cocoa is grown traditionally or extensively based on agroforestry systems (Tsouga, 2014; Fonkeng, 2015; Cerda *et al*., 2017) and presents a great intra-plot cocoa yield variation (Jagoret *et al*., 2017). Here, factors cannot be accurately determined and farm management practices and multiple bio – physical factors can either limit or enhance growth and productivity, leading to a great yield gap among cocoa farms (Aneani and Ofori – Frimpong, 2013; Asare *et al*., 2016; Jagoret *et al*., 2017), hence the need to address this yield gap.

The study therefore seeks to answer the main research question which is; what is the yield response in relation to farm management practices and bio – physical factors variation? To this main question are associated the following sub-questions:

(i) would good farm management practices increase cocoa yield?

(ii) does floristic complexity affect yield?

(iii) does soil fertility and plant nutritional status affect yields?

Hence, the general objective of this study will be to determine the effects of management options and some farm bio – physical factors on cocoa yields of cocoa agroecosystems in the Ntui locality.

Specifically, the study seeks to:

- Evaluate management practices of selected cocoa agroecosystems;
- Determine the biological diversity and the structure of selected cocoa agroecosystems;
- Determine the soil fertility and nutrient uptake of selected cocoa agroecosystems.

I. 2. LITERATURE REVIEW

I. 2. 1. Cocoa overview

I. 2. 1. 1. Distribution and main cocoa production area in the world

Cocoa is mainly produced around ‘the cocoa belt’. This ‘belt’ is situated within 10° N and 10° S of the equator. This cocoa distribution area is governed by the climatic and environmental requirements of the cocoa tree (Leitao, 2019).

Fig.1. Main cocoa producing countries in the world (map from ICCO) (Leitao, 2019)

I. 2. 1. 2. Origin

Cocoa originates from the Amazonian Forest and for many centuries before its introduction on continental Africa by the end of the 19th century, cocoa production mainly took place in South and Central America and the West Indies. From then on, cocoa rapidly expanded in Africa and since the end of the First World War, West Africa has dominated the cocoa market, unlike Congo, Liberia and the Islands of Sao Tomé (Motamayor *et al.*, 2002; Leitao, 2019).

In Cameroon, the introduction of cocoa as a crop goes as far back as the late 1800s when the German colonial authorities administered the southernmost part of the country. Since then, its cultivation has been intensively stimulated, with the then missionaries as pioneers. Cocoa pods as well as coffee seeds were selectively distributed to the employees of the missions as compensation for services rendered. These employees in turn gradually distributed cocoa seeds to relatives (Bidzanga Nomo, 2005). Cocoa seedlings were usually planted besides settlements to ensure proper management, especially during the establishment phase. The colonial authorities further reinforced this disposition when cocoa became a major subject of economic interest in the area, in order to increase control over management standards of cocoa farms during administrative inspections.

I. 2. 1. 3. Cocoa tree morphology

Cacao (*Theobroma cacao* L), is economically the most important species in the genus *Theobroma* (Vanegtern *et al*., 2015; Leitao, 2019). It was originally, an understory rainforest tree (Läderach *et al*., 2013). Most cocoa cultivation systems have been established as agroforestry systems under large forest trees canopy. More recently, monocrop plantations have been developed (Jagoret *et al*., 2017; Van Vliet and Giller, 2017). The tree grows only 4 to 6 m in height when cultivated, depending on the variety (Van Vliet and Giller, 2017). The seedlings grow 1 to 2 m in height as a single stem and then split into a jorquette (Fig. 2). A jorquette is when the stem stops developing vertically and grows into a whorl of 3 to 5 branches. These branches have a plagiotropic habit, whereas the stem and the suckers or 'chupons' have an orthotropic growth habit (Van Himme and Snoeck, 2001). The root system consists of a large taproot of 0.8 – 1.5 m and a lateral root system in the topsoil that accounts for the uptake of nutrient and moisture (Van Vliet and Giller, 2017). Young leaves are naturally pale reddish brown (Leitao, 2019). Their production occurs in 'flushes'. The flowers appear on flower pads or cushions on the truck. Under optimal conditions these cushions will continue to produce flowers for 60 to 100 years.

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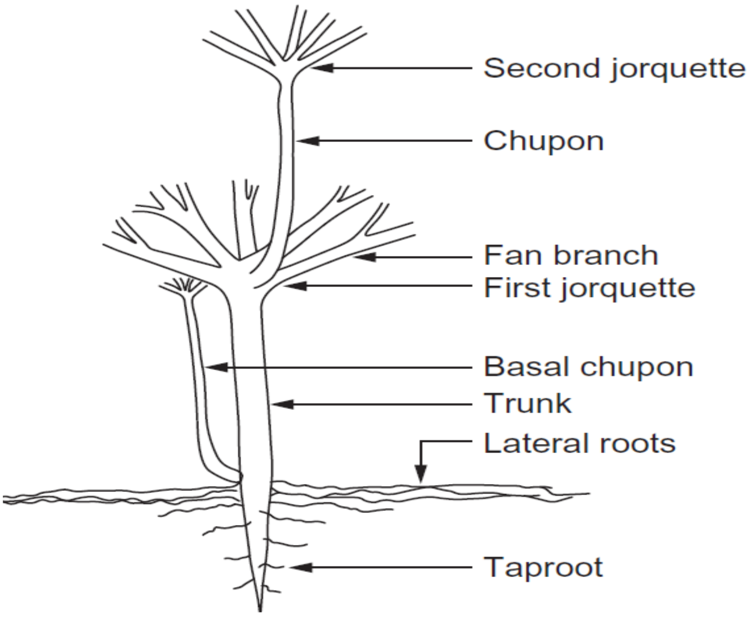

Fig.2. Schematic representation of the cocoa tree, excluding further branching and leaves (Van Vliet and Giller, 2017)

I. 2. 1. 4. Cocoa ecology

Regarding ecological requirements, cocoa grows well with temperatures between 19°C and 30°C, precipitations among 1,200 and 3,000 mm per year and a relative humidity over 70 % (Alvim and Kozlowski, 1997). Rainfall is one of the ecological factors that regulate harvest in some areas, mainly because moisture availability has a direct effect on flower and fruit formation. In most cocoa growing region annual precipitation lies between 1250 and 2800 mm. Below 1250 mm, irrigation is needed and when it exceeds 2500 mm, the effect of diseases might become higher, particularly *Phytophthora* pod rot (Landon, 2013). As stated by Wood and Lass (1985), Leitao (2019), sometimes there is a negative correlation between yield and rainfall 2 – 3 months before harvest probably because of increased fungal diseases and that, high rainfall can also cause less fertile soils because of heavy leaching.

Ideal soils should be well drained, with depth of 50 to 100 cm and good water retention capacity (Silva, 2001), rich in nutrients and organic matter (Wood *et al.*, 1987; Mossu, 1990 cited by Bidzanga Nomo 2005). However, soil permeability should not be excessive, especially in situations where there is a risk of severe or prolonged dry season. Hard lateritic concretions if present will not allow the penetration of the taproot and thus are very detrimental to the proper development of cocoa. In the wilderness the tree can reach heights up to 25 m in height, but when in cultivation, it is managed until heights of 3 to 5 m (Motamayor *et al.*, 2002).

This overview of the ecology of cocoa gives an indication of the numerous ecological factors that are necessary for an optimum growth and development of cocoa. The complexity of their interactions points to the difficulty of dissociating the effects of one factor on cocoa from the others, thus the need for an integrated approach to understanding and managing these interactions.

I. 2. 1. 5. Cocoa establishment

The dominant cultural practice of cocoa production in southern Cameroon involves planting the trees in former forestland, which has been selectively cleared and planted to various types of food crops for one or two seasons (Duguma *et al.*, 2001). The objective is to improve the soil structure and to increase the rate of infiltration of water. When land is cleared, indigenous tree species of spiritual value or socio-economic importance are deliberately maintained in the fields, alongside large to very large individuals of other species that could not be easily removed because of lack of appropriate means. Some species of socio-economic importance include indigenous fruit trees such as *Irvingia gabonensis, Ricinodendron heudelotii, Cola acuminata*; high timber value species such as *Terminalia superba, Triplochiton scleroxylon, Baillonella toxisperma, Pygnanthus angolensis, Distemonanthus benthamianus* or species of medicinal value such as *Morinda lucida, Alstonia congensis*. The field is initially planted with a mixture of 'Egussi' melon *(Cucumeropsis mannii)* and Maize *(Zea mays).* After harvesting, cocoa is inter-planted with Maize, Plantain/banana *(Musa spp)* and other food crops during subsequent farming seasons. In areas with fewer land resources as is the case for the Yaoundé block, cocoa is usually planted in long fallows, together with Plantain/banana, which serve as temporary shade to cocoa seedlings (Bidzanga Nomo, 2005). Fast growing shrubs are maintained in the field, as they will serve as permanent shade to cocoa later on. In recent years, short fallows have been increasingly contributing to the creation of new cocoa farms (Bidzanga Nomo, 2005).

I. 2. 1. 6. Soil and landscape requirements for cocoa cultivation

Soil fertility is defined here as the ability of a soil to serve as a suitable substrate on which plants can grow and develop. Fertile soils facilitate root development, supply water, air and nutrients to plants, and do not have pest and disease burdens that result in catastrophic impacts on the plants that are being grown. Maintaining soil fertility is the basis of all forms of sustainable land use, that is, land use that remains productive in the long term. If fertility has fallen below a critical level through long-term agricultural use without replacement of nutrients or as a result of erosion, or if it is naturally very low, the replenishment of soil fertility may be a precondition for productive agriculture (Schroth *et al.*, 2003).

- **Physical fertility soil characteristics**

The soils best suited for cocoa are mixtures of sand, silt and clay. Very sandy and very clayey soils are not suitable, optimum soil textures are loamy and sandy (loamy) clayey soils (Sys *et al*., 1993). In the optimum soil textures mentioned above, the finer particles are often aggregated with Fe-oxides or organic matter to form particles about the size of coarse sand. These soils possess both desirable characteristics of good drainage and aeration associated with coarse sand, and large moisture capacity associated with clay soils (Van Vliet and Giller, 2017). Organic matter content (important soil fertility characteristic) is thus an important factor, next to the clay content. Clayey soils are likely to have larger quantities of nutrients as they have a greater ability to retain them.

- **Chemical fertility soil characteristics**

  - **pH**

The pH of the soil affects uptake and availability of nutrients. The tolerated pH range is 5.5 to 7.5 with an ideal pH of 6.5 (Van Vliet and Giller, 2017). Within 1 m of the surface no layer should have a pH above 8 or below 4. Soils of Alkaline pH often induce deficiencies of micro nutrients like iron, manganese, zinc. High pH for example causes malformation of the leaves due to lack of available Fe, Cu and Zn while very acid soils on the other hand can cause phytotoxic concentrations of these micro nutrients. Cocoa might be more tolerant to acid soils than many other tropical crops (Landon, 2013).

- **C/N ration and organic matter (OM)**

Soil organic matter (SOM) is the organic matter component of soil, consisting of plant and animal detritus at various stages of decomposition, cells and tissues of soil microbes, and substances that soil microbes synthesize. SOM provides numerous benefits to the physical and chemical properties of soil and its capacity to provide regulatory ecosystem services (Tsouga, 2014). Large amounts of nutrients, and in particular N, are present in the soil in organic form. Organic matter improves the structure of the soil, facilitates aeration, and determines the capacity of the soil to hold water and exchange nutrients (Wood, 1985a reviewed by Van Vliet and Giller, 2017). Soil organic matter plays a crucial role in maintaining soil fertility, with most of it found in the top soil and it is strongly positively correlated with total nitrogen, organic phosphorus, cation exchange capacity and the sum of exchangeable bases (Van Noordwijk *et al*., 1997; Van Vliet and Giller, 2017).

Ideally, the organic matter content in the top 15 cm should be > 1.75% organic carbon (OC) (or 3% OM) (Landon, 2013). According to Sys *et al.* (1993), optimum values for OC should be > 1.5%, ideally > 2.4%. C/N ratio is an important value to distinguish rich from poor soils for cocoa cultivation, when examining agricultural land. The lower limit of the C/N ratio in the upper 15 cm soil layer is 9. When organic matter content is too low and C/N drops below 10, there might be enough N available but the storage of nutrient bases will rapidly diminish. Yet, when underlying soil layers are high in nutrients, a C/N below 9 should not be problematic. A ratio above 14 is also not desirable. These high ratios often occur in areas of high rainfall and acid soils. Yield is positively correlated with the C/N ratio and the organic matter content of the top 15 cm at the soil surface, while organic matter content in the top 15 cm should ideally be ≥ 3% (Landon, 2013).

- **Sum of basic cations, K, Mg, Ca, Na**

To achieve high productivity, cocoa requires a soil abundant in nutrients (Landon, 2013). The importance of several other soil characteristics, such as pH and organic matter, is largely due to their influence on the availability of nutrients. When it comes to basic cations, the ratio of the monovalent (K + Na) to divalent (Ca + Mg) is an important factor, having influence on plant growth and development. The ratio should not exceed 1:50 (Sys *et al*., 1993). According to Anonyme (2008) the optimum K/Ca/Mg ratio as a percentage of the sum of those three cations (expressed in cmol (+) kg^{-1} soil) is 8: 68: 24; moreover, base saturation should be at least 50 – 60 %. The optimum levels of exchangeable cations are: Ca ≥ 8 cmol (+) kg^{-1} soil; Mg ≥ 2 cmol (+) kg^{-1} soil; K ≥ 0, 24 cmol (+) kg^{-1} soil (Sys *et al.*, 1993; Landon, 2013). The sum of basic cations should be at least 4 cmol (+) kg^{-1} soil, even > 6.5 cmol (+) kg^{-1} soil for highly suitable soils for cocoa cultivation.

I. 2.2. Cocoa farm management practices

I. 2. 2. 1. Planting densities and yields

According to Van Himme and Snoeck (2001) optimum planting density provides the maximum yield per unit area over a given period. Several factors influence this spacing, particularly the plant material, tree vigor and conditions of soil, climate and shade. For example, when environmental conditions are less optimal, denser planting is recommended to achieve this maximum yield per area. In general planting density should be such that the canopy of the plantation closes as quickly as possible.

Van Himme and Snoeck (2001) advise density range of 952 to 1333 seedlings per hectare with staggered planting. A spacing of 3 x 3 m or 3.5 x 3 m is suitable for fertile soils in areas with adequate rainfall. On poorer soils, or where the climate is relatively dry, a spacing of 3 x 2.5 m is preferable. They state that previously higher planting densities were used up to 1666 plants per hectare. Anonyme (2008) recommends similar densities, again depending on soil fertility and climate conditions. In some regions cocoa yields can be optimized by implementing high planting densities (1736 – 2500 trees ha^{-1}) (Badrie *et al.*, 2015).

I. 2. 2. 2. Shade management

The problems of cocoa shading are very complex. It is clear that shade is indispensable for young cocoa. Also, the poorer the soil and the more adverse the climatic conditions, the more necessary shade becomes (Van Himme and Snoeck, 2001). In general, shade trees reduce stress of cocoa plantations by ameliorating adverse climatic conditions and nutritional imbalances on one hand and on the other hand the trees may compete with cocoa for growth resources (Beer *et al.*, 1998). For farmers and suppliers, the main concern is arguably the productivity of the cocoa trees. Many researchers suggest the potential of good shade management in improving productivity of trees (Smith *et al.*, 2012; Blaser *et al.*, 2018; Amadu *et al.*, 2020). A good shade management will depend on spacing, density, shade cover and the species of shade trees. All these factors will influence the potential of the cocoa ecosystem on yield improvement.

The control of disease and pest incidence through shade management is another particular aspect of cocoa plantations that sparks interest among researchers (Ameyaw *et al.*, 2014; Wessel and Quist-Wessel, 2015). Shade trees reduce the transmission of windborne fungal diseases (Rice and Greenberg, 2000), the activity of mirids (Padi and Owusu, 1998 cit. Leitao, 2019) and even the incidence of two important South American cocoa diseases (witches' broom and frosty pod rot). A higher diversity in shade tree species may increase the spread of natural enemies of cocoa pests (Daghela *et al*., 2013).

When it comes to soil, shade trees may contribute to the maintenance of soil fertility. The trees take up nutrients that have been washed down into lower soils layers, returning them to the soil surface by leaf litter (Wood and Lass, 1985).

Another advantage is the reduction in fruit abortion, resulting from soil N addition by leguminous shade trees. Weed growth is suppressed (Rice and Greenberg, 2000) and insect biodiversity increases resulting in improved natural control of pest populations and pollination services (Sperber *et al*., 2004; Bos *et al*., 2007; Bisseleua Daghela *et al*., 2013). Shade trees are necessary, especially for young cocoa trees (Landon, 2013). One of the main reasons for shade during the first years is to ensure the right form of growth (Wood and Lass, 1985). A 50% shade is relatively good (meaning 50% full light) for young cocoa trees. The protection created by shade is most needed when soil conditions are least satisfactory. Therefore, it should only be reduced when soil conditions are entirely satisfactory (Wood and Lass, 1985). Otherwise, there is danger of a nutrient imbalance developing within the plant due to excessive photosynthesis (Landon, 2013).

I. 2. 3. Recent research on cocoa productivity in shaded systems

It is difficult to describe the relationship between agroforestry and cocoa productivity (i.e cocoa bean yield). Blaser *et al.* (2018) suggested that shade tree density will favor productivity (measured in yield) of cocoa farms if it is kept at around 30 % shade cover while Zuidema *et al*. (2005) suggest that productivity is not significantly affected by shade under less than 60 % shade cover, above which, productivity decreases. However, cocoa tree productivity will depend on other factors aside from shade.

Cocoa pods can be found in a cocoa tree at various development stages at the same time. A large fraction of immature pods will not reach maturity, in a process called cherelle wilt (Leitão, 2019). It can happen due to the physiological state of the tree, which can be influenced by nutrient availability, light, the age of the tree and the overall hormone balance, (Bailey and Meinhardt, 2016). Additionally, several diseases and pests may have different impact on pod losses depending on the development stage of the pods (Babin *et al*., 2012; Soh *et al*., 2013; Mahob *et al*., 2018).

In the period between pod maturity and ripeness, it is still possible to suffer loses that will affect final yields. At this stage the losses will be mostly caused by disease and pest damage. If an infection spreads across the whole pod before it is ripe, the cocoa beans can be severely damaged, leading to yield losses.

As previously described the age of the cocoa trees will also have an effect on the productivity of those trees (Obiri *et al*., 2007; Wessel and Quist-Wessel, 2015). Within the same farm it is still possible that not all cocoa trees were planted at the same time.Other factors can weigh on the performance of an individual tree at the farm level. The input use and management practices taken by the farmers, such as fertilizer and pesticide use, or sanitation habits will also have a direct or indirect influence on the final yields obtained in their farms (Leitao, 2019).

Pruning can also influence the amount of shade the cocoa trees are exposed to. Canopy size may be correlated with fruit bearing of cocoa trees. It is expected that a bigger canopy can produce more assimilates, consequently allocating more assimilates to the reproductive organs, while tree size can be correlated to canopy size (within the same tree species), pruning practices should also affect the size of the canopy. Therefore, it is possible to find tall trees with narrow canopies (and vice-versa) (Leitao, 2019).

It is important to understand these causal relationships between potential determining factors in order to better understand the variance found in individual tree productivity.

I. 2. 4. Pests and diseases

In Cameroon the cocoa production has almost doubled in the last decade to the current level of about 220,000 tons. The average yield is low, about 300 – 400 kg per ha. The main yield limiting factors are the age of the cocoa trees, an inadequate input supply system and climatic conditions. Pests and diseases are the cause of around 25 % of total yield losses in Ghana and 30 – 40 % in Ivory Coast, and the highest incidence of PPR is found in the shaded cocoa in Cameroon. Regular removal of infected pods and shade reduction to lower the humidity can reduce pod losses to a certain degree but usually additional chemical control by regular spraying of fungicides is needed (Wessel and Quist-Wessel, 2015).

Due to high rainfall during the cropping season the *Phytophthora* pod rot (black pod) disease causes great yield losses in the shaded (agroforestry) cocoa farms which can only be controlled by very frequent spraying with copper fungicides. This is expensive and not totally effective, and in practice little fungicide is used. The high rainfall also causes post-harvest losses due to inadequate drying and storage facilities (Wessel and Quist-Wessel, 2015).

Most farmers, however, are unable to adopt this technology because of the high costs of the fungicides and application problems (Wessel and Quist-Wessel, 2015; Mahob *et al*., 2018). As an oomycete *Phytophthora* spp. spreads more efficiently in humid conditions (Xiang and Judelson, 2014), so controlling the microclimate caused by shade trees by pruning cocoa trees, removing infected pods from cocoa trees and from the soil should help reducing its spread. Nevertheless, the most effective control so far is the regular spraying of fungicides, which may not be sustainable for small farmers (Acebo-Guerrero *et al*., 2012).

Miridae (mirids) are some of the most destructive pests affecting cocoa. They have been shown to increase mortality in very early stages of cocoa pod development (Babin *et al*., 2012; Mahob *et al*., 2018). They spread particularly well in un-shaded conditions. Although a better shade management can be effective in reducing outbreaks, insecticides are still the main form of control (Wessel and Quist-Wessel, 2015).

I. 2. 5. Relationship between soil quality parameters and cocoa yield in Cocoa ecosystems

Soil quality (SQ) is the capacity of a soil to function within ecosystem and land-use boundaries, to sustain biological productivity, maintain environmental quality and promote plant and animal health (Doran 2002; Yemefack, 2005).

A good understanding of the complex relationship between SQ and crop yield remains a critical component of site-specific management systems and land-use planning (Katalin *et al*., 2015; Tesfahunegn, 2016). Previous studies indicated that crop yield is largely determined by climate, management systems and SQ (Xia *et al*., 2015; Adeniyi *et al*., 2019). Cultivation is one of the major activities through which man has brought changes in the physical and chemical properties of soils worldwide. In many agricultural regions, land-use intensification has resulted to soil degradation (i.e., lowered soil chemical and nutrient properties); with negative consequences on crop yield (Trabaquini *et al*., 2017).

In cocoa frontiers prolonged cultivation has reduced soil fertility mainly due to ‘‘nutrient mining’’ (Dumont *et al*., 2014; Knudsen and Agergaard, 2016). Mean pH, N and exchangeable K were within recommended thresholds for cocoa cultivation in southwest Nigeria but P, SOC and exchangeable Ca_2 contents were lower than the critical thresholds (Adeniyi *et al*., 2019). Other studies reported low levels of P in West African cocoa agroecosystems (Koko, 2013; Asare *et al*., 2017) and this can be attributed to the relatively low use of mineral fertilizers. Cocoa in several growing countries in Africa is mainly produced by small-scale farmers using limited or completely no use of fertilizers (Magne *et al*., 2014; Ogunlade *et al*., 2017).

SOC content of soils deserves special attention due to its strong correlation with soil nutrient properties and cocoa yield. Mean SOC content of soils have been positively correlated with yield levels of crops (Adeniyi *et al*., 2019). Management approach involving deliberate introduction of upper canopy tree species during plantation development (as well as corresponding replacement of tree mortality) with diverse fast-growing species may provide high quality and quantity leaf litter resources, thereby enhancing SOC stock of top soils in cocoa agroecosystems (Dawoe *et al*., 2010).

Apart from leaf litter resources, it is well known that pruned and fallen tree branches also represent a substantial part of total litter production and cocoa–timber agroforests can potentially increase the longevity of the cocoa plantations, even when chemical fertilizer is not applied (Jagoret *et al*., 2011; Koko *et al*., 2013). Cocoa systems which incorporate other tree species for shade, moisture retention, restoration of soil fertility, goods for family consumption used in the farm or sold are more sustainable in the long-term and only experience a small decrease in yields over time'' (Gyau *et al*., 2014).

I. 2. 6. Yield and Productivity

Yield is defined as the yield of a cultivar when grown in environments to which it is adapted, with nutrients and water non-limiting, pests, diseases, weeds, lodging, and other stresses effectively controlled.

Three possible methods for gathering on-farm cocoa yield data exist: (i) asking farmers to report their yield; (ii) obtaining yield records from official "Cocoa Passbooks", and (iii) directly recording the number of viable, harvested pods/tree and then weighing the dried beans from these pods after fermentation(Hainmueller, Hiscox and Tampe, 2011; Asare *et al*., 2017).

Relying upon farmer self-reporting of annual farm yield can be highly inaccurate. Some reasons for these inaccuracies include farmer illiteracy, lack of farmer record keeping, and farmers' propensity to report yield based upon the average number of "bags" harvested from the farm. This is despite the fact that they do not sell their beans by the bag, but usually in smaller quantities and at multiple points in time over the course of the season. This method also requires knowledge of the area of the farm in order to be able to estimate the yield per hectare. When self-reporting is relied upon for both the area of the farm and the total cocoa harvest, the results can be highly unreliable, as work has shown that farmers tend to over-estimate the size of their farms (Hainmueller *et al*., 2011; Asare *et al*., 2017). Thus, one could argue that this method is perhaps only useful as a general or initial estimate.

The second method relies upon the Cocoa Passbook (CP), which is an officially dated record of the weight of dried cocoa beans that a farmer sells to a Purchasing Clerk (PC) at different points in the season. With each sale, the weight of the beans being sold is recorded by the PC into the farmer's CP. The farmer uses the CP to ensure that full payment is made, if money is not immediately available. It is also used to justify bonuses farmers receive from Cocoa Board after the close of the cocoa season (Asare *et al*., 2017).

The third method demands that a researcher counts and records the number of viable pods harvested from the farm over the course of the season (approximately 4 months), and directly weighs the dried beans coming off the farm after fermentation. Though highly accurate (Asare *et al*., 2017), this method is costly and labor intensive if data is to be collected from multiple farms over the full harvest period. Given the time at our disposal, data of cocoa production in this study relies essential on the first method that consists of asking farmers to report their production.

CHAPTER II. Material and Methods

II.1. Material

II. 1. 1. Description of the study zone

II. 1. 1. 1. Localization

The study was conducted in the Ntui subdivision, situated in the Mbam and Kim division of the Center region, 100 km away from Yaoundé. The municipality covers a surface area of 1,650 km^2, extends between latitude 4° 27' 0.00" N and longitude 11° 37' 59.99" E. The population is estimated at 20,000 inhabitants with twenty-seven (27) villages and three (03) 2nd degree chiefdoms (Anonyme, 2016).

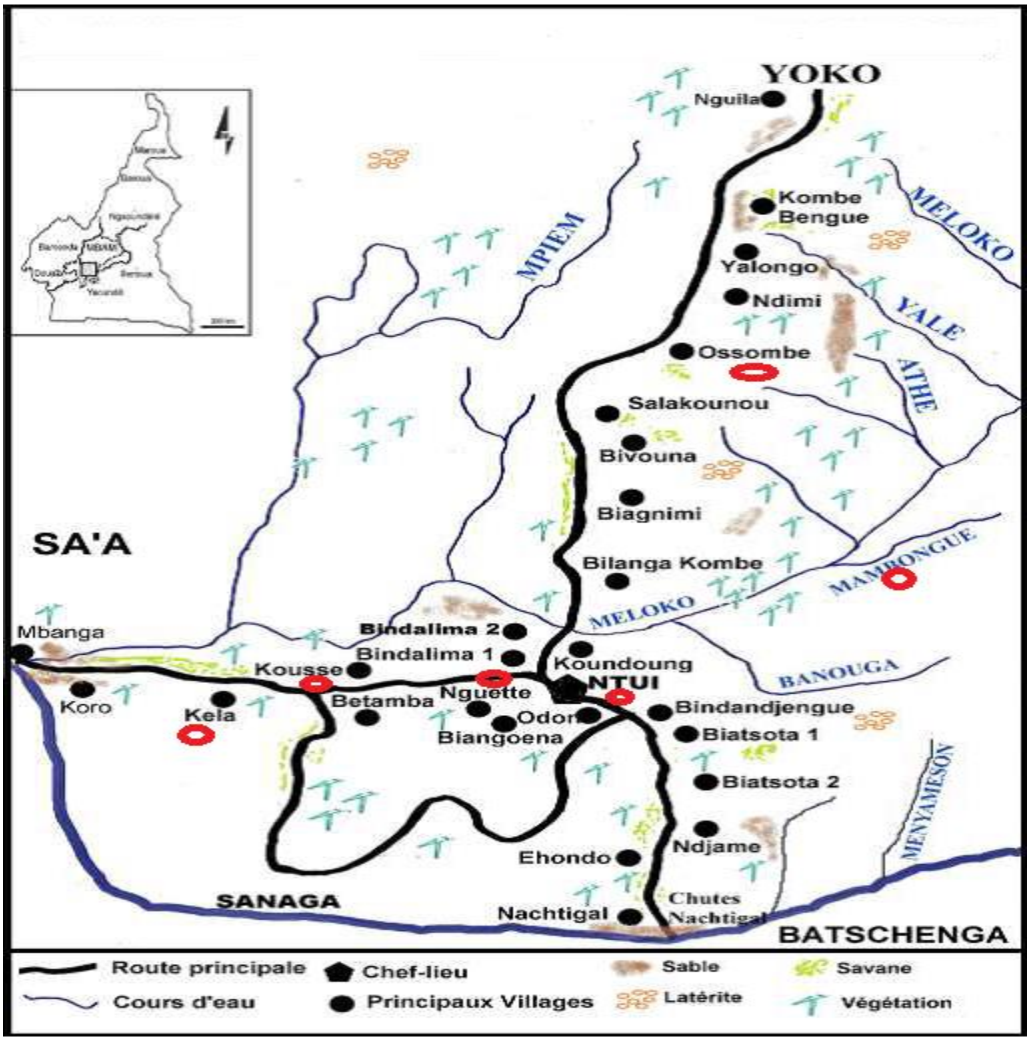

Fig. 3. Localization of study site (PDC, 2016).

II. 1. 1. 2. Biophysical description

The climate in this zone is of the Guinean subequatorial type with two rainy seasons and two dry seasons. The average temperature of the region hovers around 26 °C. Annual precipitation is from 1500 mm to 2000 mm of rain per year; the long dry season runs from mid-November to mid-March, the short rainy season runs from mid-March to mid-June, the short dry season from mid-June to mid-August and the long rainy season from mid- August to mid-November (Tarla, 2015 and Mvondo *et al.*, 2018).

The region has remarkably good arable soils with satisfactory drainage. Soil are ferralitic, acid, clayed and have a small retention capacity of nutritive elements and vegetation type is a transition zone between forest and savanna (Mvondo *et al.*, 2018).

II. 1. 2. Field and laboratory equipment

The other materials used in this work are described in the following table.

Table I: List of field work material

No	Item/Tool	Use
1	Machettes	for plots delineation
2	100 meter tape	for the measurement of the sampling plot
3	Flagging tape	for tracing the boundary of plots
4	Data collection forms	to record data
5	Soil auger	for soil sampling
6	A3 Enveloppes or paper bags	to carry soil samples from sampling site to the laboratory
7	Sticks paper	to label soils samples bags
8	Electronic balance	for the weighing of soils samples
9	diameter tape	for the measurement of shade trees diameter
10	Calliper	for the measurement of cocoa trees diameter

As far as laboratory work is concern, the following material was used:

- an oven used in the drying of soils and cocoa leaf samples;
- a porcelain mortar and pestle use for the grinding soils samples;
- an electronic balance, use in measuring the different samples proportions used in all the different manipulations;
- a pH meter, use for pH determination of soils samples;
- an electrical heated digestion block with 42 holes for the digestion tubes use in the digestions of the digest during the determination of total N and total P;
- Some digestion tubes use in to contain the digest, beaker, pipettes.

II.2. Methods

II.2.1. Determination of farm management factors

Semi - structured questionnaires were administered to farmers. They were queried about land use and management practices, such as input use, land use history and yields obtained in their farm. The survey was divided into 4 sections:

- Section 1: Land use;
- Section 2: Management practices;
- Section 3: Disease and pest management;
- Section 4: Income and cocoa yield.

II. 2. 2. Characterization of cocoa agroecosystems

II. 2. 2. 1. Experimental device and installation

As endogeneity and sample selection are major concerns with regard to non-experimental data, the following experimental device was used (Richardson *et al.*, 2009; Manga *et al.*, 2020).

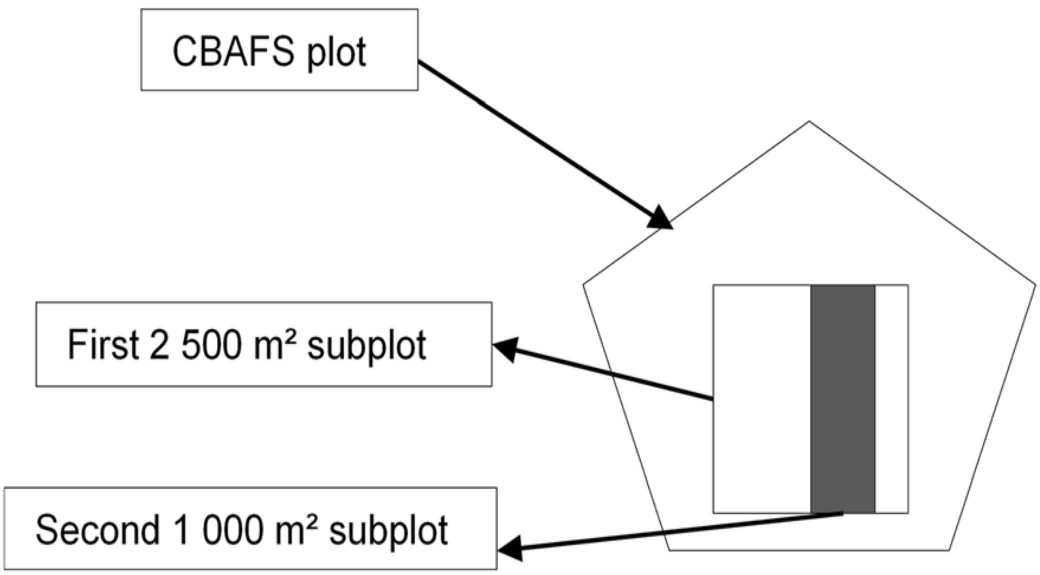

Fig.4. Experimental design

Following the interview with farmers, thirty (30) plantations were selected following a yield gradient (Low Yields (LY) and High Yields (HY). In each selected cocoa plantation, an in-depth assessment was conducted to select one cocoa plot per farm, inside which a 2 500 m^2 subplot was selected for specific farm characterization. Here, all individual trees associated with cocoa trees was identify, counted and the following information was collected: species name (Vivien and Faure, 1985), diameter, living or cut, traditional uses (food, fuel wood, timber, crafts, medicinal, edible caterpillar host), ecological services (e.g., soil fertility, humidity, shade), origin of the species (grown naturally/preserved or introduced).

The canopy cover (CC) of these shade trees was determined as followed:

For all shade trees, the Crown Diameter (CD) was measured four times across the crown spread from one tip to the other (Blozan, 2006, Asare *et al*., 2019). The average CD for the tree was calculated. The Crown Area (CA) of individual trees was calculated using the following formula:

$$\text{CA}= \pi * \left(\frac{CD}{2}\right)^2 \qquad (1)$$

CA is expressed in m^2. The total CC for all the upper canopy trees was expressed as a percentage of farm area to ensure easy comparison between farms, using the following formula:

$$\text{CC}= \frac{TCA}{Farm\ size}100\% \qquad (2)$$

Where TCA is the total CA of all trees recorded per farm and farm size is expressed in m^2.

The species identifications were based on vernacular names with assistance from the farm owner and correspondences with the scientific names was established from literature review.

A second 1000 m^2 subplot, in which records information (cocoa tree densities, height, DBH, pruned or not, the cocoa LAI (Leaf Area Index)) was recorded on all cocoa trees, was included in the first subplot (Fig. 4).

II.2.3. Determination of the soil fertility and cocoa tree nutritional status of cocoa agroecosystem

II. 2. 3. 1. Soil sampling and analysis

At each 1000 m^2 subplots (Fig. 4) 30 core samples were collected at every 30 m apart in a Zig-Zag pattern to ensure homogeneity in each subplot at a depth of 0-30 cm. This was done after removal of surface litter at the sampling spots because nutrient stocks are restricted to the upper 30 cm, as most feeding roots of cocoa are concentrated to that depth.

The core samples were later mixed together giving a composite sample and 500 g of each composite sample was measured, package in paper bags and taken to the laboratory for analysis. In the laboratory the composites samples were subjected to the following analysis: Sand, Silt and Clay percentages, Total N, Available P, exchangeable bases (K, Ca, Mg and Na), pH, and Organic Carbon.

Soils was air-dried and ground to pass through a 2 mm sieve. For C and N analysis, soils were further fine ground to pass through a 0.5 mm sieve. Soil pH in water was determined in a 1:2.5 (w/v) soil: water suspension. Organic C was determined by chromic acid digestion with heating and spectrophotometric analysis (Heanes, 1984). Total N was determined from a wet acid digest (Buondonno *et al*., 1995) and analyzed by colorimetric analysis (Anderson and Ingram, 1993). Exchangeable cation (Ca, Mg, K and Na) was extracted using ammonium acetate at pH 7 and analyzed by AAS. Available P extracted using Bray-1 and analyzed using the molybdate blue procedure described by Murphy and Riley (1962). Particle size (three fractions) was determined by the hydrometer method

II. 2. 3. 2. Foliar diagnosis

As far as the cocoa tree nutritional status is concerned, foliar diagnosis (Renato de Mello and Gustavo Caione, 2012) was done in the month of October. A pair of leaf was taken from 25 cocoa trees at the opposite from the different treatment making a total of 30 samples. In order to have a good representative mineral status of cocoa trees, leaves should be collected from August to October in the morning before half past ten (10h 30). Second and third leaves were collected on the cocoa branches from the apical end. Cocoa branches should be aged from ten to fourteen weeks and leaves should be mature and characterised by brown color of pulvinus on the upper side and brown and green color on the lower side. Cocoa branch would also have green and sectors. Collected leaves were washed, wipes and introduced in numbered plastics bag and taken to the laboratory for analysis.

In the laboratory, after controlling the pulvinus coloration, leaves were cut into two, along the central rib and only half of this blade was dried at about 70 °C, crushed, stored on dry room in labeled paper bags and later used for the different analysis. Analysis concerning Total N, Total P, and Exchangeable basis (K, Ca, Mg and Na) were carried out.

The soil and leaf tissues analysis were carried out at the IITA Analytical laboratory in Yaoundé, Cameroon using the international norms (www.iita.org).

II. 3. Data collection

Both qualitative and quantitative data were collected. Two types of data were necessary for this study; secondary and primary data

II. 3. 1. Primary data

Primary data were collected at the level of cocoa farmers and cocoa plantations. One hundred (100) cocoa farmers were interviewed to capture farmer's management practices. Field data soils and cocoa leaves tissues samples were collected from thirty (30) Cocoa plantations.

Cocoa yield data were obtained by asking farmers to report their production for the last consecutive three (03) years (Asare *et al*., 2017). The yield was then obtained by simply dividing the production by the total surface area of each cocoa agroecosystems studied. Besides 'Yield' other variables were defined to characterize the structure and status of the cocoa stand, as well as for the associated tree communities.

Cocoa stands were characterized by;

- Cocoa tree density(ha^{-1}), measured by counting cocoa trees located in the 1000 m^2 quadrat.
- Mean age(years) of cocoa trees calculated on the basis of the age of each cocoa tree indicated by the farmer.
- Mean area(m2), of the cocoa agroecosystems indicated by the farmer.
- The mean height (m) of cocoa tree crowns measured using a graduated gauge. This variable is an indicator of cocoa tree growth and varies according to the cropping and environmental conditions (Jagoret *et al*., 2017).
- Cocoa plant DBH, average height of cocoa tree (m), cocoa plant density (tree/ha), LAI (Leaf Area Index), Canopy cover (%), shade trees density (tree/ha), shade tree diversity (species/ha), farm surface area and age of the cocoa trees as far as the cocoa agroecosystem's characteristics are concern.
- Sand, Silt and Clay percentages, Total N, Available P, exchangeable bases (K, Ca, Mg and Na), pH, and Organic Carbon as far as soil/ecological properties are concern.

II. 3. 2. Secondary data

Secondary data was obtained from different principal sources; documentation obtained from resource persons (students, teachers and researchers), online publications on the internet and libraries of research institutions whose activities cover our research topic. Consultation of documents from CIRAD, IRAD, IRD, IITA and CRESA libraries were therefore of great importance for the collection of such data.

II.4. Statistical analysis

Data collected were initially registered in a Microsoft excel spreadsheet and the grouped data imported into the R package ordering R 3.5.2 software for analysis (R Development Core Team, 2019). The survey data were subjected to descriptive statistics (percentage of each category of variable, (Numerical summary: Mean, Median, Quartile, coefficient of variation, tables and graphs) to assess the variability among ecological factors and farm management practices that affect cocoa yield and inferential analysis.

Correlation using the Pearson's correlation coefficient at a threshold probability of P value < 0.05 analysis was performed to segregate the most significant correlations between all variables. Then, a principal component analysis (PCA) was conducted to identify the main correlations between variables. Relationships between cocoa yield, farm management practices, cocoa agroecosystems characteristics and soil properties (of high loading factors in the PCA as independent variables and cocoa yield as dependent variable) were determined by multiple linear regressions with forward stepwise variable selection.

To satisfy the assumption of multiple regressions, yields factors included in the regression model were checked for normality using the Shapiro – Wilk test test (P = 0.05) and when necessary, the data were subjected to logarithmic transformations. The derived regression model was formulated as:

Y = f (X1, X2, X3, ……………….. Xn + e)

Where,

Y = Cocoa yield (Kg ha-1)

X1, X2, X3, ……………….. Xn: denote the different factors

e = Error term

CHAPTER III. RESULTS AND DISCUSSION

III.1. Results

III. 1. 1. Cocoa agroecosystem management practices

III. 1. 1. 1. Farmer's profile and cocoa yield

Results obtain from our study shown that; respondents consisted of males (95 %) and females (5 %). Concerning the marital status, 45% were married and some of the farmers thou not married were in couple (35 %). Also, generally the educational level of the farmers was moderate with more than 50 % of the farmers having at least secondary level of education and only 1 % with no education at all. In term of cocoa farm acquisition mode, results reveal that, most farmers obtained their plantation by planting it themselves.

Table II : Summary of respondents demographics and farms characteristics

Characteristics		Percentage (%)
Sex (count)	Male	95
	Female	5
Marital Status (count)	Single	15
	Married	45
	Widow	5
	En couple	35
Educational level (count)	No school	1
	Primary	44
	Secondary	51
	University	4
Origin (count)	Native	63
	Foreigner	37
Duration of stay in the village (count)	Since birth	56
	Since….Years	44
Membership of a farmer's group or association (count)	Yes	76
	No	24
Mode of farm acquisition (count)	Creation	64
	Heritage	34
	Bought	2
Age of plantations (years)	Less than 10 years	16
	10 – 20 years	50
	20 – 30 years	18
	30 – 40 years	9
	More than 40 years	7

Results from analysis as illustrated in table III which presents the summary of additional farm characteristics of the respondents reveals that, the average age of the respondents was 46 years, with a range of 24 – 79 years. The average year of farming experience was 18 years, with a range of 4 - 57 years. The mean farm size in hectares (ha) of the cocoa producers was 3.32. The average cocoa yield was 630.1 kg/ha, with a minimum value of 105 kg/ha and maximum value of 1365.3 kg/ha.

Table III : Summary of farmers and farm characteristics of the respondents in the study areas

Characteristics	Sample size (n)	Mean	Minimum	Maximum
Age of farmers (years)	100	46	24	79
Experience in cocoa farming (years)	100	18	4	57
Total size of cocoa farm (ha)	100	3,32	0,5	12
Cocoa yield (Kg/ha)	30	630, 1	105	1365, 3

III. 1. 1. 2. Farm's characteristics and land-use management

As shown in table IV results reveals that, most of the farmers' (64 %) both had the hybrid and the Non – hybrid varieties in their plantation, nevertheless survey results shown that, most plantations are dominated by the hybrid species present in high proportion (68 %). Also, a high proportion of the farmer's investigated obtained their planting material from neighboring plantations (66 %), against those (28 %) who obtained from other sources such as IRAD, SODECAO or MINADER.

Regarding farm rehabilitation, 96 % of farmers interviewed have rehabilitated their plantation, against 4 % who have not, with the under-planting method being the main rehabilitating method. Also, majority of the plantations (83%), were established under vegetation (forest or savanna) 75 % space cocoa trees irregularly in their plantations, against 25 % plantation with a regular spacing (Table IV).

Concerning the seedling transplanting methods, the mains one's practice by farmers are; bare – root seedling (59 %) and potted seedling (35 %), while most of the farmers (55 %) plant their cocoa tree at a distance of 2,5 m*3 m between and within the lines.

As observed from data analysis, among the entire farmer's investigated, 64 % perceive no change in the soil fertility status over the last 10 years, against 18 % that perceive a decrease and 16 % who perceive an increase. Overall, 49 % farmer's appreciation of the current status of the soil fertility of their plantation was moderate, against 41 % who consider it to be high and 10 % low.

Table IV: Description of land – use management characteristics

Characteristics		Percentage (%)
Variety of cocoa grown (count)	Local	11
	Hybrid	25
	Mixte	64
Variety in high proportion (count)	Hybrid	68
	Non – Hybrid	32
Source of planting material (count)	Neighbor farm	63
	Own farm	6
	Other sources (IRAD, SODECAO, MINADER)	36

Land – use before planting cocoa (count)	Open field	1
	Forest	83
	Other crop	14
	I don't know	2
Seedling transplanting method (count)	Bare – root seedling transplant	59
	Direct seeding	6
	Potted seeding	73
	Do not know	2
Type of spacing practice in cocoa plantation (count)	Regular	25
	Irregular	75
Distance between cocoa trees(count)	1 m * 2 m	16
	2 m * 2 m	24
	2.5 m * 3 m	55
	3 m * 4 m	2
	Do not know	3
Have you rehabilitated your plot(count)	Yes	96
	No	5
If yes, what is the rehabilitation method used(count)	Under planting	95
Appreciation of the current status soil fertility of plantation(count)	Low	10
	Moderate	49
	High	41
Perception in any change in soil fertility status over the last 10 years(count)	It has increased	16
	It has decreased	18
	There was no change	64
	I don’t know	2
Overall, do you think your cocoa trees are healthy and strong (count)	Yes	72
	No	28
Major soil conservation practices (count)	No soil conservation method	89
	Agroforestry	11
Application of chemical fertilizer (count)	Yes	80
	No	20
Method of chemical fertilizer application (count)	Ring method	1
	Broadcasting	2
	Spraying	76
Utilization of organic fertilizer(count)	Yes	0
	No	100
Type of weeding practices (count)	Manual Weeding	94
	Weeding using herbicide	6
If manual weeding, frequency of weeding(count)	2 times per year	43
	3 times per year	47
	4 times per year	6
Pruning frequency (count)	Every time need be	22
	Once every two years	15
	Once every year	36
	twice a year	14
Reason for pruning (count)	Sanitaion	36
	Shade Management	84
	Other, Give shape to the cocoa tree	4

III. 1.1.3. Inputs management

- **Pest and disease management**

  - **Major cocoa causing disease agent**

Overall, 74 % of the farmers investigated affirmed that their cocoa trees are healthy, while the remaining 26 % said the contrary. Survey results indicate that, dieback (42 %) is the main cocoa disease that affect cocoa agroecosystems (Fig. 5).

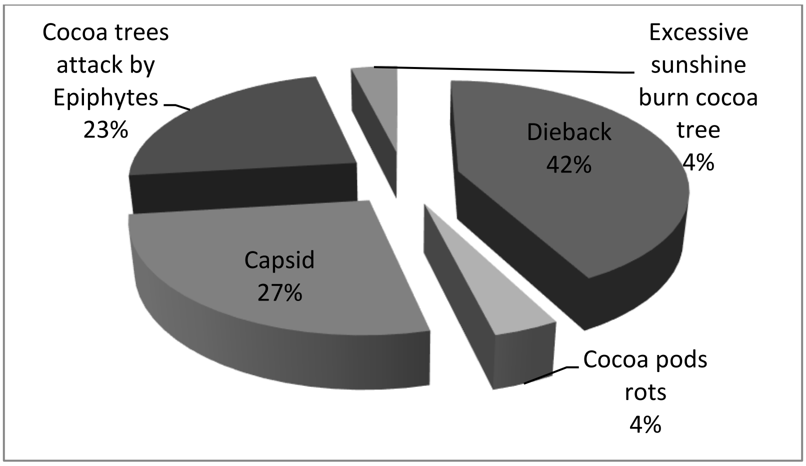

Fig.5. Major cocoa causing disease agent

  - **Insecticide application**

Result from survey, after analysis indicates that, 99 % of farmers apply insecticide on their cocoa plots against 1 % who do not, with the main insecticide formulation used by farmers being Imidaclopride 20 g/l+ Lambdacyhalothrine 20 g/l (46 %) (table V). These farmers apply averagely 2, 7 L/ha of insecticide, with minimum quantity applied being 0, 4 L/ha and the maximum being 12 L/ha.

Table V: Insecticide active ingredient used by farmers

Insecticide's active ingredient	**Proportion (%)**
Chlorypyriphos-ethyl	14
Imidaclopride 20 g/l+ Lambdacyhalothrine 20 g/l	46
Imidaclopride 30 g/l	6
Imidaclopride 30 g/l + lambda-Cyhalothrine 60 g/l	13
Cyperméthrine	1
Thiamethoxam	9
Thiamethoxam 30 g/l + Lambda - Cyhalothrine 60 g/l	9

Concerning the insecticide period of application, results indicates that, insecticides are mostly applied during the long dry season with a peak on March (35 %) (Fig.6).

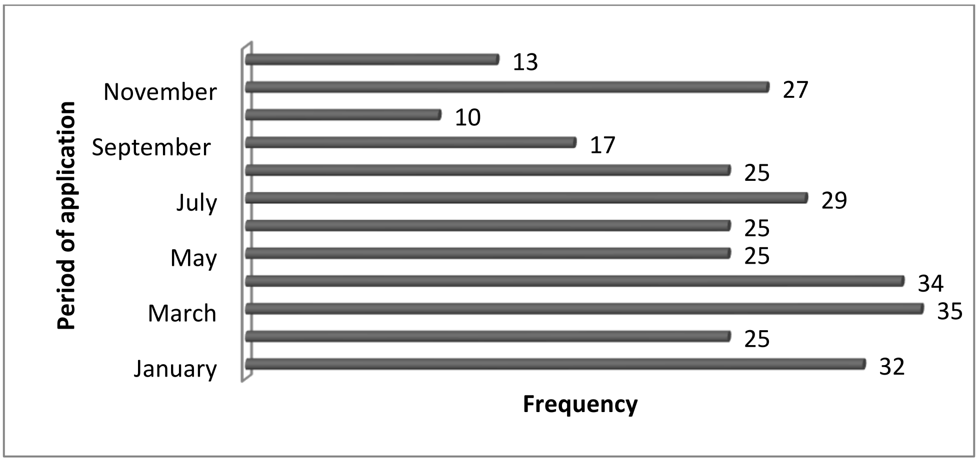

Fig.6. Insecticide periods of application

- **Fungicide application**

Result from survey, after analysis indicates that, 99 % of farmers' use fungicide on their cocoa plots against 1 % who do not, with the main fungicide formulation used by farmers being Metalaxyl -M 6 % + Oxyde de cuivre 60 % (63 %) (table VI). These farmers apply averagely 42 sachets/ha of insecticide, with minimum quantity applied being 6 sachets/ha and the maximum being 150 sachets/ha.

Table VI: Fungicide active material used by farmers

Fungicide active material	**Proportion**
Cymoxamil 120 g/kg + Oxychlorure de cuivre 700 g/kg	2
Dimenthomorphe 120 g/kg + Oxychlorure de WP 600 g/kg	2
Hydroxyde de Cuivre 538 g/kg	1
Metalaxyl -M 6 % + Oxyde de cuivre 60 %	63
Metalaxyl M- 60 g/kg + Oxyde de Cuivre 60 g/Kg	2
Metalayl - M 60 g/kg + Oxyde de Cuivre 600 g/kg	20
Nepic stimular	1
Oxyde de Cuivre 86 %	8

Overall, farmers apply fungicides throughout the whole year but the main period of application correspond to the long rainy season with a peak during the month of September (86 %) (Fig. 7).

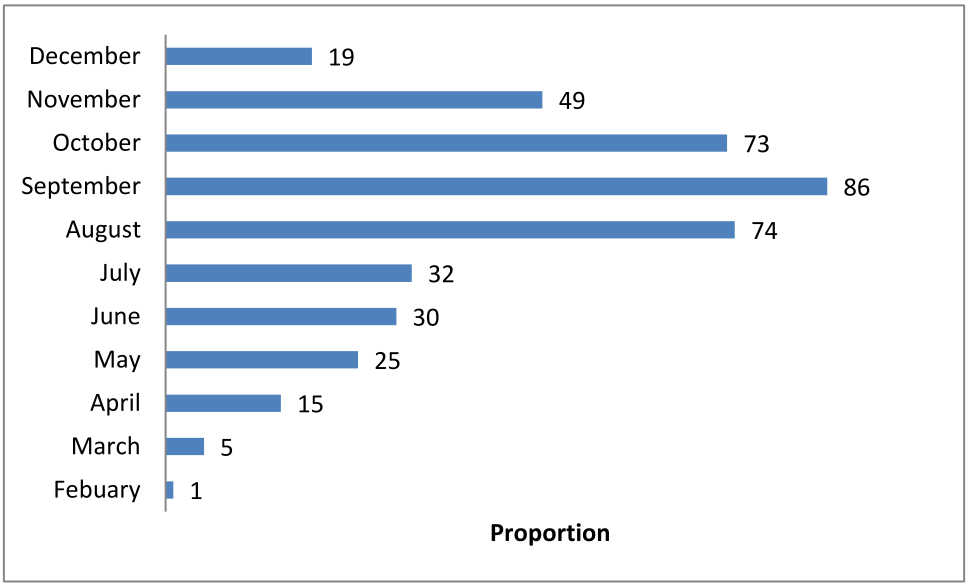

Fig.7. Fungicide periods of application

- **Fertilizer application**

Result from survey indicates that, 73 % of farmers apply chemical fertilizers on their cocoa plots against 27 % who do not and they mainly apply foliar fertilizer type, with N 15 - P 15- K 30 (31 %) and N 20 – P 20 – 20 K (34 %) being the main formulation used by the farmers. These farmers apply averagely 1, 72 kg/ha of the fertilizer, with minimum quantity applied being 0, 25 kg/ha and the maximum 8 kg/ha. Also, no farmers interviewed apply organic fertilizer.

The application of chemical fertilizer during the last two years was done at a frequency 6 times and above (49 %) (Fig. 8).

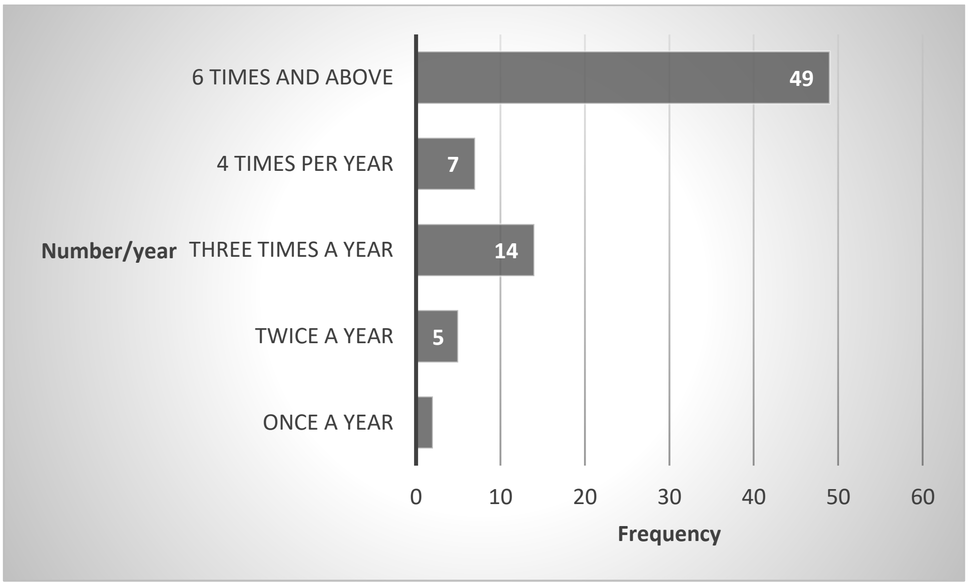

Fig.8. Frequency of application of foliar fertilizers

III. 1. 2. Biological diversity and the structure of cocoa agroecosystem

Results from analysis indicate that, the studied cocoa agroecosystems are very heterogeneous with considerable variation of the various parameters among the different plantations (Table VII). In total 525 shade trees were recorded on a total of 7, 5 ha sub-divided into two main groups vis: (i) permanent shade tree species and, (ii) temporary shade trees species. The permanent shade trees species component comprised 51 species from 44 families with 86 % being forest trees species and the remaining 14 % fruit tree species. The most occurring species included timber species like *Terminalia superba* Engl. & Diels (5 %), *Milicia excelsa* (Welw.) C.C. Berg (5 %), *Polyalthia suaveolens Engl. & Diels* (4 %), *Pycnanthus angolensis* (3 %). Fruit trees such as *Dacryodes edulis* (8 %) *Persea Americana* Mill (7 %) and the temporary shade *Musa sp.* (23 %) were the most common. Analysis showed that tree diversity on the farm plots increased with increasing farm size.

Figure VII: Structural characteristics of studied cocoa agroecosystems

Farm parameters	**n**	**Mean**	**Min**	**Max**	**Sd**	**CV (%)**
Cocoa plant DBH (cm)	30	83,05	31,07	139,23	19.40	31.07
Average height of cocoa tree (m)	30	5	2.79	8.8	1.37	27.40
Cocoa plant density (trees/ha)	30	1445	726	2948	500.24	34.61
Cocoa LAI	30	14,61	10.7	19,78	1.85	12.68
Canopy cover (%)	30	28,11	3,79	100,75	25.60	91.07
Shade trees density (tree/ha)	30	52	12	128	31.01	59.79
Shade tree diversity (species/ha)	30	31	8	72	15	48.35

n = number of cocoa plots investigated; Min = minimum values; Max = maximum values; sd = Standard deviation; CV = Coefficient of variation

III. 1. 3. Soil fertility and cocoa nutritional status of studied cocoa agroecosystems

III. 1. 3. 1. Soil property variation and interrelationship

Results from analysis demonstrate that, on average all the soils are sandy clay loam soil. The pH of the investigated soils ranges from 4, 69 – 7, 81, with mean value of 5, 96. This mean value indicates that, in general the pH of these soils is suitable for cocoa cultivation. Result also shows that, overall, the investigated soils are lacking in their nutrient elements (table VIII). For instance, organic carbon content ranges from 0, 85 – 1, 98 with mean value of 1, 28 which is fall below the critical value for cocoa cultivation. Same applies for N, P and Ca, while k with range of 0.015 – 0.404 and mean value of 0.111 fall above the critical value for cocoa cultivation.

Table VIII: Soil property variation

Parameters Soil (0 – 30 cm)	**Minimum**	**Maximum**	**Mean**	**SD**	**CV (%)**	**Threshold ***
Sand (%)	33,97	79,75	58,48	11,27	19,3	
Silt (%)	7,35	31,50	12,93	5,07	39,2	
Clay (%)	10,90	54,39	28,38	11,88	41,8	
$pH_{(water)}$	4,69	7,81	5,96	0,78	13,2	5.6–7.2
Organic Carbon (%)	0,85	1,98	1,28	0,30	23,2	2.03
Total Nitrogen (%)	0,07	0,17	0,11	0,03	25,1	0.09
C:N Ratio	9,38	16,84	12,03	1,65	82,1	
Bray P (ug/g)	0,32	4,94	1,77	1,21	68,4	10
Exchangeable K (cmol(+) kg-1)	0.015	0.404	0.111	0.087	78,3	0,03
Exchangeable Ca (cmol(+) kg-1)	1.14	16.19	4.64	3.54	76,3	7.5
Exchangeable Mg (cmol(+) kg-1)	0.31	3.02	1.22	0.61	49.4	0,8
Exchangeable Na (cmol(+) kg-1)	0,01	0.05	0.01	0.012	82.1	

n =30, number of cocoa agro – ecosystems sampled, Sd = Standard deviation, CV = Coefficient of Variation

** Threshold values of chemical content in cocoa leaves relevant for cocoa cultivation (Aikpokpodion, 2010)*

III. 1. 3. 2. Cocoa leaf tissues nutrient composition

Results from analysis as presented in (Table IX) reveals that except for potassium and available phosphorous, all the other nutrient elements had their mean nutrient content above the critical level.

Table IX: Chemical properties of cocoa leaf tissues

Selected properties of leaf tissues	**Mean**	**Minimum**	**Maximum**	**Sd**	**CV (%)**	**Threshold ***
Total N (%)	1,78	1,44	2,16	0,17	10	0.9 %
Available P Bray P (ug/g)	0,12	0,09	0,15	0,02	14.14	0.2 %
K (%)	1,46	0,85	2,21	0,46	32.1	2 %
Ca (%)	1,31	0.61	1.99	0.36	27.63	0.6 %
Mg (%)	0,64	0,29	0,91	0,12	19.42	0.5 %

n=29, number of cocoa plantations samples, Sd = Standard deviation, CV = Coefficient of Variation
** Threshold values of chemical content in cocoa leaves relevant for cocoa cultivation (Aikpokpodion, 2010)*

III. 1. 4. Relationship between estimated cocoa yield, farm management practices and some bio - physical parameters

As can be seen from the correlation table in Annex 3 that, estimated cocoa yields increase significantly with cocoa agroecosystem surface area (r= 0,7087; p= 0.0001) and the variety of cocoa grown (r = 0.6769; p = 0.0003). Average cocoa yield shows a negative correlation with associated trees densities (r = -0.7148; p = < 0.0001), plant diversity (r = -0.7029; p = 0.0001). Also, the application of chemical fertilizer correlated significantly with cocoa agroecosystems surface area (r = -0.7514; p = < 0.0001), as well as the quantity of chemical fertilizer applied (r = -0.8128; <0.0001). Regarding soil nutrient content, $pH_{(water)}$ correlated significantly with calcium (r = 0.8684; p = < 0.0001), as well as organic carbon and total nitrogen (r = 0.8211; p = <0.0001), while sand and clay correlated significantly but negatively (r = -0.9051; p = < 0.0001).

III. 1. 4. 2.

Regarding the PCA results, according to the Kaiser rule, only dimensions having an Eigen value > 1 should be selected and described. Theoretically we can select up to the 7th dimension because they have an eigen value greater than 1. But as the purpose of the PCA is to reduce the dimension in order to explain the variance among the population, we only interpreted the first two dimensions. They both explains around 35.62 % of the total variance (Fig. 9). In these results, the first principal component has positive correlation with total nitrogen, CcoDBH, clay, pH, magnesium, calcium, CcoHei, potassium, CcoAge, QtyFungiAp, FSA, ExCF and a negative correlation with C/N, CcoDens, TRESpe, LAI, TREDens and sands. CPA 2 axes on the other hand associates positively with organic carbons, calcium, phosphorous, total nitrogen, potassium, clay, FungiFreqA but associates negatively with FungiApA, QtyFungiAp, silt and CcoAge. Also, cocoa yield which is our target variable positively associates with CcoAge, QtyFungiAp, FSA, CcoDBH, CcoHei, hence will increase alongside their increase. On the other, cocoa yield associates negatively with phosphorous, TREDens, LAI, TRESpe and will turn to decrease as these parameters increases.

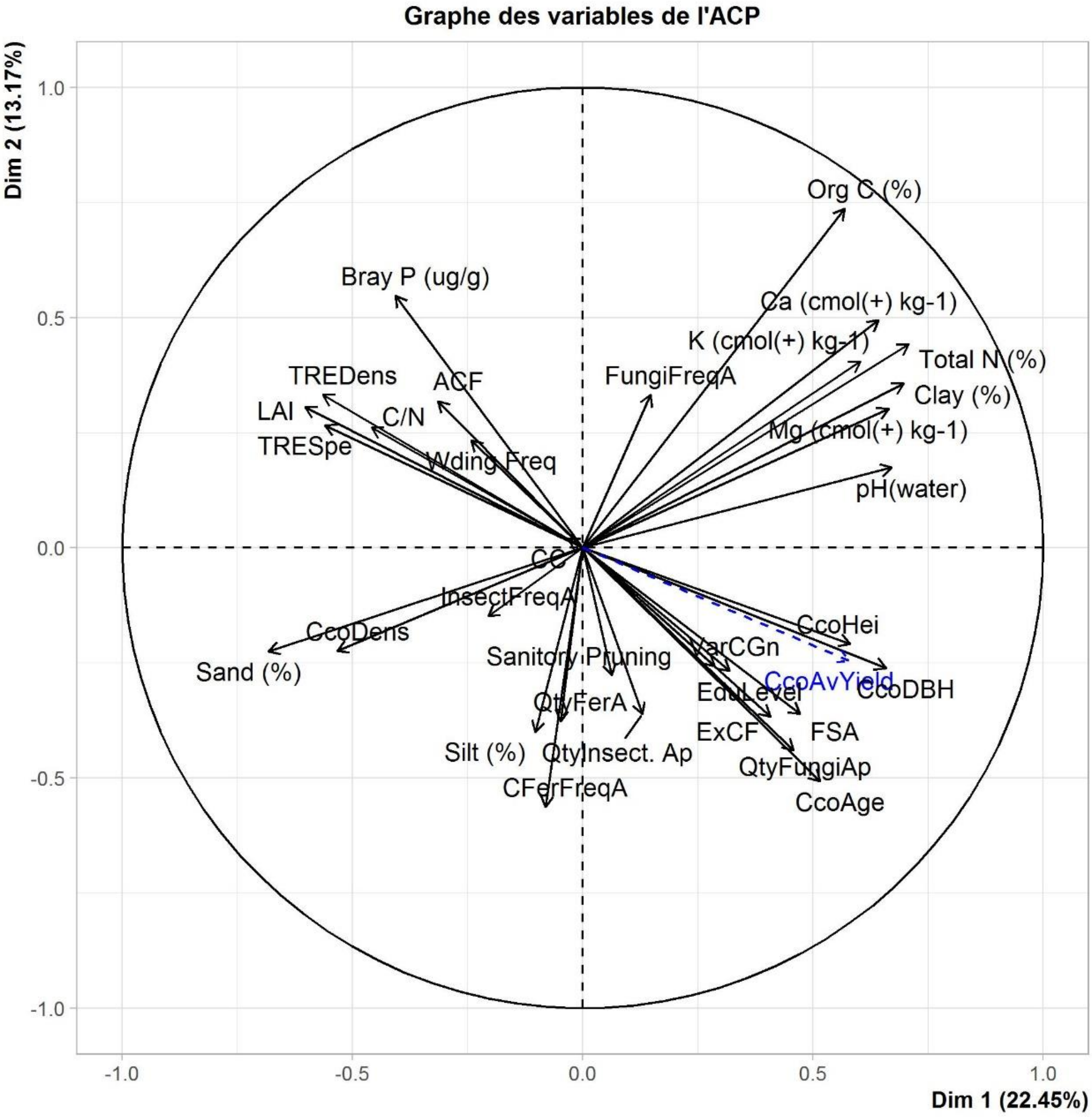

Fig. 9: Principal component analysis with yield component variables, cocoa stand structural variables and soil fertility parameters. Yield (blue line) was projected as a supplementary variable.

From the regression outcome (Table X), the F -statistics of 4.133 was statistically very significant ($P < 0.05$), indicating a joint influence of the independent variables and that the model existed. The R-squared was 0.782, implying that 78.2 % cocoa yield variation explained by the factors combined. The constant term was significant (P < 0.05). Also, variables such as potassium and associate's trees species densities had significant negative impact on the cocoa yield. Concerning the associate's trees species densities, the negative implies that as trees densities increased by one-unit, cocoa yield decreased by 12,61 kg/ha.

Table X: Results of multiple linear regression analysis

	Model : Cocoa yield			
Independent variables	Estimate	Std. Error	t-values	Pr (>|t|)
(Intercept)	3704.554	1619.359	2.288	0.037*
Ca (cmol/kg)	−2.396	60.858	−0.039	0.969
CcoDBH	−5.361	4.676	−1.146	0.230
Clay	−10.934	14.645	−0.747	0.467
FungiFreqA	48.024	64.365	0.747	0.467
InsectFreqA	−93.648	50.473	−1.855	0.083˙
K (cmol/kg)	−3857.970	1187.336	−3.249	0.005**
LAI	−35.430	49.271	−0.719	0.483
Mg (cmol/kg)	299.769	152.579	1.965	0.068 ˙
Org C (%)	−143.909	564.718	−0.255	0.803
pH $_{(water)}$	74.242	291.984	0.254	0.803
Sand	−22.397	18.975	−1.180	0.256
Total N (%)	1620.872	5134.833	0.316	0.757
TREDens	−12.608	2.983	−4.227	0.0007***

Residual standard error : 302.2 on 15 degrees of freedom
Multiple R-Squared : 0.7818
Adjusted R-Squared : 0.5926
F-Statistic : 4.133 on 13 and 15 DF
p-value : 0.005

*Note : **P < 0.05, *** P < 0.01. CcoDBH : cocoa tree diameter at breast height, FungiFreqA : fungicide frequency of application, InsectFreqA : insecticided frequency of application, LAI : leaf area index, Org C : organic carbon, TREDens : Associates trees species densities.*

Finally, a stepwise variables selection (direction = backward/forward; criterion = 'AIC') revealed that, insecticide frequency of application, potassium, LAI, magnesium, sand and associate's trees species densities were the only measured variables that remained in the final model such that:

Y= 2610.11InsectFreqA – 3261.078 K (cmol/kg) – 40.981 LAI + 270.719 Mg (cmol/kg) – 9.381 Sand – 11.744 TREDens

3. 2. Discussion

3. 2. 1. Cocoa agroecosystem management practices

3. 2. 1. 1. Cocoa yield, farmers and farm characteristics

The estimated mean cocoa yield obtained was 630.1 kg/ha. This was higher than values usually obtained through surveys for cocoa agroforests in central Cameroon that is 264 kg/ha (Duguma *et al*., 2001), 255 kg/ha (Jagoret *et al.*, 2011), or elsewhere in Africa, that is, 214 kg/ha in Ivory Coast and 454 kg/ha in Ghana (Gockowski and Sonwa, 2010). This should confirm the limits of survey based on farmer's declarations that was associated to the fact that even though farmer may exactly know the quantities of cocoa they market, but often overestimated the surface area of their plantations, thus leading to an underestimation of cocoa yields, when based on survey findings (Jagoret *et al*., 2017). The differences observed in our study, meanwhile we used the same approach and that was closer to the estimated mean cocoa yields obtained by kenfack *et al*. (2020) can be explained by the fact that, certain cocoa buying firm present in the field through their certification activities use GPS device to measure farmers plantations, hence most farmers now our day have an exact estimate of their plantations surface area. The yields were closer with the yields estimated by Jagoret *et al.* (2017) on the basis of pod counts, that is 737 kg/ha.

As far as gender is concerned, 95 % of farmers were male against 5 % female; indicating that cocoa is still predominantly male activity and mean age of the farmers was 46 years. This mean age fall within the old age group 41 – 60 years that has been registered in many socio – economic studies (Aneani *et al*., 2012; Baah and Asamoah, 2013; Abdulai *et al*., 2020; kenfack *et al.*, 2020). This is a worrying situation to some aged farmers since the future of their cocoa farms depends on the interest of the youth who are their potential heirs as noted by Kenfack *et al*., 2020. Educational status of the farmers was moderate, as 50 % of had a secondary level of education and 4 % with a university level. These findings are different from earlier studies (Aneani *et al*., 2012; Baah and Asamoah, 2013; Abdulai *et al*., 2020; kenfack *et al*., 2020). Most of the farmers are members of a farmers group (76 %) and on average had 18 years experiences in the management of cocoa agroecosystems.

3. 2. 1. 2. Land-use management

Cocoa farms are established on forest galleries or on savanna. The results show that all the farmers who declared to apply chemical fertilizer on their plantations do apply only foliar fertilizer hence, highlighting the fact that, farmers in the study area do not apply granular fertilizer. As reported by MINADER, (2018), few cocoa farmers used mineral granular fertilizers, mainly because they could not afford them. Also, (Hartmink, 2006; Vanlauw *et al*., 2010) highlighted the high cost of fertilizers as a barrier to their utilization. According to Wilson *et al*., (2019), farmers may see investing in fertilizer risky given the large annual and inter – farm variation in cocoa yields. The role of social learning in behavior construction highlighted by Bandura and Walters, (1977) and stated in kenfack *et al*., (2020), who, in his study found that, besides the price of cocoa, farmers declared they do not use mineral fertilizer because their parents made a living out of cocoa farming without using them and this can further explain the non-utilization of granular fertilizer.

Furthermore, there was no correlation between fertilizer application and cocoa yield and this may further be explained by the fact that, the manner in which these fertilizers are applied does not actually contribute substantially to the plant nutrition. This is in line with Magne *et al*., (2014) who reported that most farmers in southern Cameroon use no fertilizers and Kenfack *et al*., (2020). Consistently, studies have reported that most Nigerian cocoa farmers do not use chemical fertilizers (Ogunlade *et al*., 2017; Adeniyi *et al*., 2017).

Also as reported by farmers in kenfack *et al*., (2020) study on farmer's perceptions as a driver of agricultural practices, many of the farmers in this study also mixed fertilizer with insecticide or/and fungicide during treatment and this may compromise the effectiveness of the plant protection reagent as noted by (Griffith,2010; Gandini *et al*., 2020).

The quantity of fungicides applied was the only farm management practice that showed a positive correlation with yield. This result is consistent with the result of Abdulai *et al*., 2020; who demonstrated that, in the marginal climate suitability (dry) zone, where fungicide application is expected to be low compared to the humid zone since the black pod disease (*Phytophthora megakarya*) is more prevalent, there is instead a high rate of fungicide use.

3. 2. 2. Bio-physical characteristics of cocoa agroecosystems

The mean density of cocoa stands was 1445 ± 500 trees/ ha. The values were closer to the values obtained by Jagoret *et al*., (2011) with a different experimental design but still in a forest – savanna transition ecology, and also closer to his results of (2017), with the same experimental design as the one of this study. The densities were also close to those recommended for simple cocoa cropping systems, that 1330 to 1660 trees/ha, under low interspecific competition (Wood and lass, 2001).

Results from our study show that all farms had associate's trees, but in varying numbers, resulting in shade tree densities ranging from 12 to 128 trees ha^{-1}, with mean density of 52 ± 31 trees ha^{-1} and CC, above the cocoa trees varying from 3,79 % to 100 %. This mean density is different from the values obtained by Jagoret *et al.* (2017) in Bokito who found a total of 202 trees survey from 17 and also those obtained by Abdulai *et al*., (2020). Thirty-one species, on average, were associated with cocoa trees. This value was higher than those obtained by Jagoret *et al*., (2017), that are 7 species and Abdulai *et al*., (2020) who found on average a total of 11 trees species in the mid zone between the dry and wet zone. These variations could be explained by differences in the survey methodology adopted by these authors, such as, the lower size of the quadrats in which the inventories were conducted and the thresholds of diameter at breast height they used to inventory the associated trees.

These results are in accordance with other studies that demonstrated that, in Cameroon cocoa is commonly grown as complex agroforestry systems were cocoa is associated with forest or fruit tree species that farmers preserve and/or plant after partial forest clearing (Jagoret *et al*., 2014; Sonwa *et al*., 2014). These trees provide several benefits to the cocoa plantations as well as to the farmer (Tsouga, 2014; Jagoret *et al*., 2017). However, these trees – crop association can result to competitions, which may lead to the reduction of cocoa yield if the degree of shade and tree density is not well managed. This was revealed in our study with the significant relationship of the increasing associate's trees density and plant diversity with the decreasing cocoa yield.

3. 2. 3. Soil property variation and relationship with cocoa yields

The variability of soil properties has been demonstrated by several authors in the past. For instance, Adeniyi *et al*., 2018, inspired by Aweto (1982) ranking of soil properties variability in southwest Nigeria who considered a CV of less than 20 % as showing little variation, between 20 and 50 % as moderately variable, and a CV exceeding 50 % as highly variable. If applied to the studied soil, the CV of most of the selected soil parameters studied exceeds 50 %, hence the soils are highly variable and this may further explain the difference in the yield among farmers. The CV of the physical soil properties is lower than that of the chemical soil properties, with sand having the least variable (19. 3 %). This confirms the findings of Adejuwon and Ekanade's (1988) and those of Adeniyi *et al*., 2018 that, soils under similar vegetation in the same topographical location have similar characteristics. In contrast the CV of Silt (39. 2 %), Clay (41. 8 %), and Organic carbon (23. 2 %) and total Nitrogen (25. 1 %) display moderate variability. A relatively high CV was recorded for exchangeable potassium (78. 3 %), calcium (76. 3 %) and sodium (82. 1 %), except for exchangeable magnesium (49. 4 %). This confirms the finding of Aweto (1982) that, the soils possess high variability in macronutrient properties but the results are different from those of Adeniyi *et al.*, 2018 who obtained low CV for soil exchangeable cations in his study area.

A good understanding of the complex relationship between soil quality and crop yield remains a critical component of site-specific management systems and land use planning (Katalin *et al.*, 2015; Tesfahungegn, 2016). Previous studies indicated that crop yield is greatly determined by climate, management systems and soil quality (Tchienkoua *et al.*, 2008; Xia *et al*., 2015).

CHAPTER IV. CONCLUSION AND PERSPECTIVES

IV. 1. Conclusion

The study seeks to answer the main research question that was; what is the yield response in relation to ecological and farm management practices? To answer this question, it was necessary to evaluate farm management practices and determine bio – physical parameters of cocoa agroecosystems. This study highlights the large variations in smallholder farmer cocoa yield gaps and yield gap determining factors in a forest – savanna transition zone.

It was shown based on correlation analysis that, cocoa yield is mostly determine by bio – physical factors as compared to farm management practices. Result from regression analysis indicated that, frequency of spraying insecticide against capsids, the soil fertility parameters: potassium; magnesium, the soil structural parameter sand, the cocoa leaf area index and the associates tree species densities had a significant impact on cocoa yield and were the only measured variables that remained in the final model. This implies that, poor management of soil potassium and magnesium content of the studied soils and an increase in associate's tree density are likely to be responsible for yield decline.

Hence a better management of associate's trees of cocoa agroecosystems and the control of soil Ca content of the study zone should be taken in consideration. Also, farmers need to adopt and respect better farming management practices.

The indication of the huge yield variation amongst farmers by this study challenges research institutions, universities and cocoa developmental agencies to encourage cocoa farmers through pragmatic measures t adopt the yield – increasing technologies of cocoa production to minimize excessive land expansion and consequently

IV.2. Perspectives

Further study on wider sample of cocoa agroecosystems could be carried out to confirm this work.

Also, further study that will take in consideration a detail soil analysis and the utilization of a more efficient method for the gathering data on yield could be carried.

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Annex

Annex 1. Questionnaires

This questionnaire aims to obtain data on cocoa farm management practices. The information collected will be used to write an MSc thesis with a view to obtaining the Research Master degree in Plant Biology; Option: Botany and Ecology. The results of this survey are confidential and will be used only for academic purposes.

SECTION 1: IDENTIFICATION OF THE STUDY ZONE

Date:………………………………………
Locality: ………………………………..
Subdivision:………………………………..
Division:……………………………………
Region:
……………………………………………….

SECTION 2: HOUSEHOLD INFORMATION

1. Sex: 1. Male; 2. Female
2. Age of respondent (years)
3. Marital status: 1. Single; 2. Married; Divorce; 4. Widow
4. Educational level: 1. No School; 2. Primary; 3. Secondary; 4. University; 5. Professional training; 6. Other …………..
5. Origin : 1. Native ; 2. Foreigner
6. How long have you been living in the village: 1. since my birth; 2. after my retirement; 3. Since …….. month; 5. Since …… years
7. Number of years in Cocoa farming?.............
8. Are you a member of a farmers' group or association? Yes/No
9. In how many groups or association are you?............
10. For how long have you been a member? ………… years

SECTION 3: LAND USE/ MANAGEMENT PRACTICES

1. How many cocoa plots do you have? ……………………..

Surface area: ……………………………. (Most important plot)

2. Age of cocoa plantation?

(Select one: a. less than 10 years; b. 10-20 years; c. 20-30 years; d. 30-40 years; e. more than 40 years)

3. Variety of cocoa grown/Planting material: 1. Local; 2. Hybrid, 3. Other (Specify) ………………….
4. Source of the variety/planting material: 1. Neighbor's farm; 2. Own farm; 3. others (specify) ………….
5. What was there in the field before the current cocoa trees were planted?
   (Select one: a. open field; b. forest; c. other crop (specify); d. I don't know)
6. How did you plant your cocoa seedlings?

1. Bare – root seedling transplant; 2. Direct seeding; 3. Potted seeding; 4. Others; 5. Do not know

7. What type of spacing do you practice in your cocoa farm?

1. Regular; 2. Irregular

8. What is the distance between the cocoa trees?

(1. cm; 2. m; 3. Pole; 4. Rope, 5. Other) …….

9. Have you rehabilitated this plot? Yes/N

If yes, which method of rehabilitation are you engaged in? (Select one: a. under planting; b. gradual planting; c. complete replanting; d. no rehabilitation)

10. When did you last replant? (Select one: less than 5 years; 5-10 years; 10-15 years; 15-20 years; 20-25 years; more than 25 years)
11. Why did you replant? (Select one: a. cocoa trees over-aged; b. cocoa trees diseased; c. others (specify))
12. Overall, how do you appreciate the current status of soil fertility of your cocoa plantation? (Select one: a. low; b. moderate; c. high)
13. Do you perceive any change in soil fertility status over the last 10 years? (Select one: a. It has increased; 2. It has decreased; 3. There was no change; 4. I don 't knows)
14. Overall, do you think your cocoa trees are healthy and strong? (Yes / No) If 14=no: What is causing that (specify)
15. Major soil conservation practices: 1. No soil conservation; 2. Mulching; 3. Fallow; 4. Agroforestry; 5. Others (specify)…………
16. Do you use chemical fertilizer? (Yes/no) If 16 = yes

a. When was the last time you applied chemical fertilizer? (Specify in months and year)

b. How frequently did you apply chemical fertilizer in the last two years (number of times per year)? (Select one: a. once a year; b. twice a year; c. three times a year; d. other (specify))

c. Name of chemical fertilizer:………………………………………

d. Quantity applied on this plot (Kg, liter, others specify) ……………………….

e. Method of application: 1. Ring method; 2. Broadcasting; 3. Spraying

f. Period of application: …………………………………………….

17. Do you use organic fertilizer? (Yes/No)

a. Major organic fertilizer applied on the field: 1. Crop residues; 2. Animal manure; 3. Home – made compost; 4. Others (specify)…………………………………………….

18. Do you use herbicide for weed management? (Yes/No) If 18= yes

a. When was the last time you applied chemical fertilizer? (Specify in months and year)

b. How frequently did you apply chemical fertilizer in the last two years (number of times per year)? (Select one: a. once a year; b. twice a year; c. three times a year; d. other (specify))

c. Name of herbicide:……………………………………………

d. Quantity applied on this plot (Kg, liter, others specify)………………………..

e. Method of application: 1. Ring method; 2. Broadcasting; 3. Spraying

f. Period of application: …………………………………………….

19. Do you remove epiphytes from cocoa trees? (Yes/No)

20. What do you do with opened pods?

(Multiple selection: a. leave in field; b. remove from field; c. other (specify))

21. Do you prune cocoa trees? (Yes/No), If 21 = Yes

a. Why do you prune your cocoa trees?

(Multiple selection: a. Sanitation; b. Shade management; c. other (specify))

b. How often do you prune the trees? (Specify)

SECTION 4: PEST AND DISEASE MANAGEMENT

1. Do you use insecticide? (Yes/No), If 1= Yes

a. Which insecticide(s) do you use? (Specify the name)

b. Amount of insecticide applied in 18/19 season: (specify the number of units)

c. Unit of measurement for amount.

(Select one: a. Kg; b. g; c. L; d. bags; e. other)

d. When was the last time you applied insecticide? (Specify the month and year)

e. How frequently did you apply insecticide in the last two years (specify)

f. Do you use insecticide on shade trees? (Yes/No)

2. Do you use fungicide? (Yes/No), If 2 = Yes

a. Which fungicide(s) do you use? (Specify the name)

b. Amount of fungicide applied in 18/19 season: (specify the number of units)

c. Unit of measurement for amount.

(Select one: a. Kg; b. g; c. L; d. bags; e. other)

d. When was the last time you applied fungicide? (Specify the month and year)

e. How frequently did you apply fungicide in the last two years (specify)

f. Do you use fungicide on shade trees? (Yes/No)

a. How do you dispose of diseased pods?

b. When was the last time you removed diseased pods? (specify. Hint* in days)

c. How often do you remove diseased pods? (Specify. Hint* every (x) days/weeks/months)

3. Do you remove diseased pods from the cocoa trees? (Yes/No), If 3= yes

(Multiple selection: a. leave in field; remove from field; other (specify))

4. Do you “sterilize” your tools used for managing diseased trees before using them on healthy trees?

(Select one: a. always; b. frequently; c. rarely; d. never)

5. Do you practice mulching in your cocoa crops? (Yes/No), If 5 = Yes

a. Which material (s) do you use for mulching? (Specify)

6. Do you consider *Phytophthora* pod rot (aka black pod) to be a threat to your cocoa crops? (Yes/no), If 6= yes

a. In a scale of 0 – 5 how would you classify this disease’s effect?

(Select one: a. 0; b. 1; c. 2; d. 3; e. 4; f. 5)

b. Besides fungicide application, what other strategies do you use against black pod (if any)? (specify)

7. Do you consider mirids to be a threat to your cocoa crops? (Yes/No), If 7= yes

a. In a scale of 0-5 how would you classify this pest’s effect?

(select one: a. 0; b. 1; c. 2; d. 3; e. 4; f. 5)

b. Besides insecticide application, what other strategies do you use against mirids (if any)? (Specify)

8. What other pests/diseases do you perceive as important in your cocoa crops? (Specify)

9. What other pest/disease management strategies do you apply in your cocoa crops (if any)? (Specify)

SECTION 4: INCOME AND COCOA YIELD

Years	Total of dry beans harvested in last three seasons (16/17; 17/18; 18/19) **(in bags)**	Weight per bag of dry beans (**in Kg**)	Total of dry beans sold in the last three seasons (**in bags**)
16/17			
17/18			
18/19			

1. Do you think shade tree products are important for the economy of your household?

(Select one: a. 0; b. 1; c. 2; d. 3; e. 4; f. 5)

2. How has cocoa quantity sold changed over time (5 years)?

(Select one: 1 = increased; 2 = decreased; 3= no change)

a. What are the 3 most important reasons for the change? (specify)

Annex 2: List of names and frequency of shade trees found in the shaded plots across all 30 farms assessed in the Ntui sub – division.

No	Local Name	Scientific Names	Family	Frequency
1	Abang	*Milicia excelsa*	Moraceae	24
2	Abel	*Cola accuminata Schott& Endl.*	Sterculiaceae	14
3	Acouk	*Alstonia bonei*	Apocynaceae	3
4	Adjab/Moabi	*Baillonella toxisperma Pierre*	Sapotaceae	1
5	Akom/Ilandi	*Terminalia superba*	Combretaceae	31
6	Akpwa'a	*Tectrapleura tetraptera*	Mimosaceae	1
7	Akui	*Xylopia aethiopica*	Annonceae	5
8	Andoi Ntangani	*Mangifera indica*	Anacardiaceae	5
9	Asang	*Irvingia gabonensis*	Irvingiaceae	3
10	Atui	*Piptadeniastrum africana*	Mimosaceae	2
11	Ayous	*Piptadeniastrum africana*	Sterculiaceae	3
12	Azobe	*Triplochyton scleroxylon*	Ochnaceae	3
13	Banana/Plantain	*Musa sp.*	Musaceae	6
14	Bete	*Mansonia altissima*	Sterculiaceae	7
15	Boumé/Douma	*Ceiba pentandra*	Bombacaceae	21
16	Bubinga	*Guibourtia demeussei*	Fabaceae	1
17	Corrosolier	*Annona muricata*	Annonaceae	1
18	Ekui			4

19	Elen	*Elaies guineensis*	Arecaceae	15
20	Epok	*Entandrophrama angolensis*	Meliaceae	13
21	Eseng	*Musanga coecropioides*	Cecropiaceae	1
22	Eteng/Calbot	*Pycnanthus angolensis*	Myristicaceae	20
23	Evoule	*Vitex doniana Sweet*	Verbenaceae	5
24	Evovone	*Spathodea campanulata*	Bignoniaceae	1
25	Eyong	*Eribroma oblonga (Mast) Pierre*	Sterculiaceae	2
26	Ficus	*Ficus mucoso*	Moraceae	1
27	Intousi			1
28	Itoh	*Voacanga africana*	Apocynaceae	1
29	Kadi			1
30	Macore	*Tieghemella africana*	Sapotaceae	1
31	Mpoule	*Enantia chlorantha*	Anacardiaceae	1
32	ND			6
33	Ndamba(Hivea sauvage)	*Funtamia elastica*	Apocynaceae	6
34	Nganga	*Polyalthia suaveolens Engl. & Diels*	Annonaceae	21
35	Ngolon	*Maesopsis eminii Engl.*	Rhamnaceae	1
36	Ngome leboume	*Hevea brasiliensis*	Apocynaceae	1
37	Ngon	*Klainedoxa gabonensis*	Irvingiaceae	1
38	Njansang	*Ricinodendron haudelotti*	Euphorbiaceae	15
39	Nom Abang	*Morus mesozygia*	Moraceae	2
40	Nom Eyen	*Pericopsis elata*	Papilionaceae	1
41	Nourga	*Anthocleista vogelli*	Loganiaceae	2
42	Odim			5
43	Okokoro			1
44	Opouma/Mandarin	*Citrus sinensis*	Rutaceae	15
45	Opouma/Orangier	*Citrus recticulata*	Rutaceae	2
46	Padouk	*Pterocarpus sp.*	Fabaceae	1
47	Pia	*Persea americana*	Lauraceae	36
48	Popo	*Carica papaya*	Caricaceae	5
49	Sa'a/Ibanou	*Dacryodes edulis*	Burseraceae	41
50	Saliyeme	*Albizia adianthifolia*	Mimosaceae	3
51	Sayeme	*Albizia zygia*	Mimosaceae	8
52	Thoime			1
53	Zolebi	*Bosqueia angolensis*	Moraceae	5
Total				377

Annex 3: Relationships between soil parameters and cocoa yield

Variables	Sand	Silt	Clay	SOC	Total N	C/N Ratio	P	pH(H2 O)	Ca	Mg	K	Na
Silt	-0.135											
Clay	**-0.895**	-0.321										
Organic carbon	**-0.657**	-0.271	**0.75**									
Total Nitrogen	**-0.740**	-0.123	**0.762**	0.901								
C/N ratio	**0.462**	-0.281	-0.315	-0.159	**-0.563**							
Bray P	0.332	-0.141	-0.254	-0.231	-0.279	0.269						
pH(water)	-0.091	-0.240	0.204	0.330	**0.451**	**-0.406**	-0.210					
Ca	**-0.399**	-0.271	**0.503**	**0.634**	**0.726**	**0.423**	-0.207	**-0.847**				
Mg	**-0.566**	-0.063	**0.569**	**0.574**	**0.623**	**-0.406**	-0.328	**0.610**	**0.697**			
K	**-0.468**	-0.02	**0.456**	**0.582**	**0.577**	-0.222	-0.289	**0.403**	**0.470**	**0.620**		
Na	-0.0998	**0.621**	-0.184	-0.187	-0.194	0.037	-0.023	-0.385	-0.301	-0.089	-0.074	
Cocoa yield	- 0.347	0.189	0.247	0.083	0.247	- 0.379	**- 0.475**	**0.519**	**0.453**	0.264	0.208	0.03

Annex 4. Component Matrix of variables on the first five principal components (PCA)

Variables	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5
CcoHei	0.567820787	-0.22958016	0.21420035	0.278343219	0.19966519
LAI	-0.593892180	0.30543295	0.19024084	0.379021452	-0.11573320
CcoDBH	**0.660745742**	-0.26106911	-0.03713147	0.400334509	-0.15631158
FSA	0.475655052	-0.37129478	-0.31512047	0.426358493	0.11046464
CcoDens	-0.532961402	-0.22201951	0.49950148	-0.185571686	0.39341563
TREDens	-0.562861549	0.34477163	-0.04821927	0.082020002	-0.49446465
TRESpe	-0.552844821	0.27213655	-0.16866585	-0.176419161	-0.37371325
CC	-0.034559955	0.02970912	0.50784797	0.360047214	-0.06386970
pH.water.	**0.665836992**	0.16914460	0.25209055	0.054669827	0.49746859
Ca..cmol....kg.1.	**0.637937283**	0.48580014	0.13850116	-0.047163061	0.35188148
Mg..cmol....kg.1.	**0.663871961**	0.32755039	0.10218936	-0.178228953	-0.09814171
K..cmol....kg.1.	**0.601875455**	0.41227181	-0.06439034	-0.348622661	0.06609094
Org.C....	0.563262107	**0.74280229**	0.03616942	-0.104178770	-0.00936434
Total.N....	**0.705632611**	0.46086547	0.28482382	-0.165785117	-0.15838668
C.N	-0.460179550	0.24945404	-0.50277805	0.187352199	0.18328144
Bray.P..ug.g.	-0.407054040	0.52510271	-0.20559479	0.006800017	0.31282309
Sand....	**-0.686149679**	-0.23809406	0.06121169	0.196893142	0.46607650
Clay....	**0.698683235**	0.37434551	-0.06020454	0.032092616	-0.43009651

Silt....	-0.096805226	-0.40808418	0.07484376	-0.535931997	-0.09892697
EduLevel	0.320016621	-0.24903860	0.48610546	-0.323486134	0.08838652
ExCF	0.411586204	-0.38028645	-0.46129812	0.424773948	-0.13327365
CcoAge	0.521410672	-0.50348034	-0.23362152	0.304009086	-0.22327446
VarCGn	0.293217166	-0.26984903	-0.29453476	-0.539339471	0.41752300
ACF	-0.315906592	0.32350003	0.20122672	-0.238088074	-0.26833616
QtyFerA	-0.006086366	-0.27878560	-0.33273746	-0.277896074	0.02298944
CFerFreqA	-0.085926517	-0.41059603	0.54234953	-0.262371213	-0.38822892
Wding.Freq	-0.241978068	0.21384729	0.30013854	0.155094552	0.48410457
Sanitory.Pruning	0.063261141	-0.26537754	0.30842021	-0.099949513	-0.30978037
QtyInsect..Ap	0.127497224	-0.34931303	0.43204156	0.114344277	-0.07154742
InsectFreqA	-0.211320857	-0.13297078	**0.73302031**	0.129301541	-0.06370050
QtyFungiAp	0.460019719	-0.43518360	0.07555686	-0.198943048	0.06766291
FungiFreqA	0.142960769	0.34076720	0.47261290	**0.602724924**	0.02888077