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**RESEARCH ARTICLE**

# TOWARDS SUSTAINABILITY IN SOIL FERTILITY MANAGEMENT IN COCOA PRODUCTION IN CÔTE D'IVOIRE

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**ABSTRACT**

Although Côte d'Ivoire is the first producer in cocoa, its cocoa production is made by extension while yield are still low because of soil fertility decrease, diseases and pests and planting material quality. If this can be solved by improved varieties creation, soil fertility and it management need to be treat seriously to face climate changes effects. Chemical fertilization has been tested unsuccessfully and raised others problem due to acidification and product quality. Ivoirian cocoa producers being costumed to produce without fertilizer, we aim in this test to experiment, DAF system to improve soil fertility and cocoa productivity in central Côte d'Ivoire. In an on farm trial made with 54 farmers using different cocoa varieties, no significant difference was noticed between one year DAF application and control yields even if DAF yields better. However, old plantations showed an improvement in soil organic matter content compare to their controls of same farmer. The plantation age and DAF application are the principal factors that condition the success of the system. All species associated to cocoa are useful to local people and this can made possible the rapid adoption of that innovative strategy in cocoa production and lead to better cocoa dry broad bean.



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## INTRODUCTION

Cocoa (*Theobroma cocoa* L.) is cultivated in family system agriculture in West Africa by small scale farmers. Its lifetime can reach 80 years and the multiplicity of possible associations raised many methodological difficulties to characterize and evaluate these systems' performances (Bisselua *et al.,* 2013). Indeed, African farmers associate on the same plot, cocoa with other perennial and/or annual species (Marney *et al.,* 2008). Even if many models exist today to simulate the annual crops or forest dynamics, few of them can represent the agroforests covers (Nordwijk-van *et al.,* 2004). The methods and criteria developed to evaluate intensive and monospecific systems performances seem to be insufficient and inappropriate to approach the functioning of agroforestery systems (Kumar, 2006).

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However, according to Torquebiau (2007), simple methods were recently developed to characterize this kind of cultivation system. The small farmers generally produce cocoa under shade (Vos *et al.,* 2003), in association or in semi-natural agroforestry. These production areas constitute particularly rich and stable habitats for various species maintaining a certain biodiversity (Sonwa *et al.,* 2007). Since the independences, Côte d'Ivoire largely developed the cocoa production (Assiri *et al.,* 2009). It is cultivated traditionally according to an extensive and itinerant system using vegetative material not performing (Koko *et al.,* 2013), generally uptook from existing plantations for a quality considered to be interesting by the producer. Coffee and cocoa sector has, according to a report of the IPCC (2007), a very important weight in the economy of Côte d'Ivoire. The same report indicates that, on the 3,989,578 ha occupied by exportation products, 48 % were devoted to cocoa cultivation, 26 % to coffee, 7 % to cotton, 5 % to palm tree, 7 % to cashew nut and

3 % to hevea. Côte d'Ivoire produce about 41% of the world cocoa production and it constitutes the first cash crop for the country. It accounts for 40 % of the national exportation and the national production was 1'429'244 tons 2012. Cocoa contributes to a total value of 20 % with gross domestic product (GDP) and approximately 4 to 5 million people earn live with cocoa production (ICCO, 2014). Côte d'Ivoire inherited Cocoa production from the colonial period and east and centre-east of the country, were the first cocoa zones. This zone moved gradually towards west and south-west, considered today as the cocoa principal production zones (Assiri *et al.,* 2009 and Kouakou *et al.,* 2012). These cocoa plantations represent about 16 % of the total forest cover in Côte d'Ivoire (Sonwa *et al.,* 2007). In addition, centre-west and south-east are zones of intensive cocoa production where approximately 93 % of the farmers live from cocoa. These plantations occupy in the south-west and south-east a surface of 2.5 million hectares (Kouakou *et al.,* 2012). The performances of the Côte d'Ivoire in cocoa production are honorable; however they were obtained mainly by the increase in the acreages destroying the forest (Assiri *et al.,* 2011). The retreat of the forest and the climate change make certain areas very marginal for cocoa tree growing. Consequently, since more than one decade, many constraints threaten the durability of Ivorian cocoa production. It acts in particular (Assiri. 2007) to:

- Ageing of the orchard (lack of shade and technical maintenance);
- Poor quality of the seed material associated with extensive techniques;
- Strong parasitic pressure (swollen shot) and the emergence of new pathologies;
- Low productivity estimated between 260 and 600 kg/ha/year,
- Effects of the climate changes and the soil fertility losses.

Important programs of fertilization were developed in various cocoa production areas of the country (Assiri *et al.,* 2009) in order to improve productivity. Moreover, a fertilization test with N-P-K (0 23 19) 5Mg formula was carried out during five years. The use of the chemical fertilizer in cocoa production was still very weak in Côte d'Ivoire (Koko 2007). Consequently, researchers are looking for improved practices in cocoa production. DAF system characterized by forest persistence, senescent fragments drops and regular pruning, accelerates the accumulation of organic matter on the soil (Gockowski *et al.,* 2005). The DAF practice controls cocoa productivity factors as well as the effects of the climate changes (FiBL 2012). The association of the cocoa-tree with food crop, woody species, medicinal and fertilizing species (leguminous plants), allows the diversification of the income and improves the food mode (Gockowski *et al.,* 2010). Agrobiodiversity improves soil fertility and allows fast renewal of the cycle of certain nutritive elements (Milz *et al.,* 2012, Ofori *et al.,* 2007).

**Study area**

The study was carried out in Côte d'Ivoire, in the zone delimited by western longitudes 5° and 5°45' and by the northern latitudes 6°40' and 7°. This zone covers partially the Lakes (Yamoussoukro) and Marahoué (Bouaflé) regions (Figure 1). The part study area located in the lakes region is a forest-savanna transition area. The climate is humid tropical type being characterized by an annual water average which varies from 1000 to 1400 mm (Brou, 2005), with four alternated seasons, including two dry and two rainy seasons. The soil is generally ferralsols and cambisols formed from the volcanogenic formations and gleysoils localized in the valleys or the alluvial plains (Yao-Kouamé *et al.,* 2008; Zro Bi *et al.,* 2014).

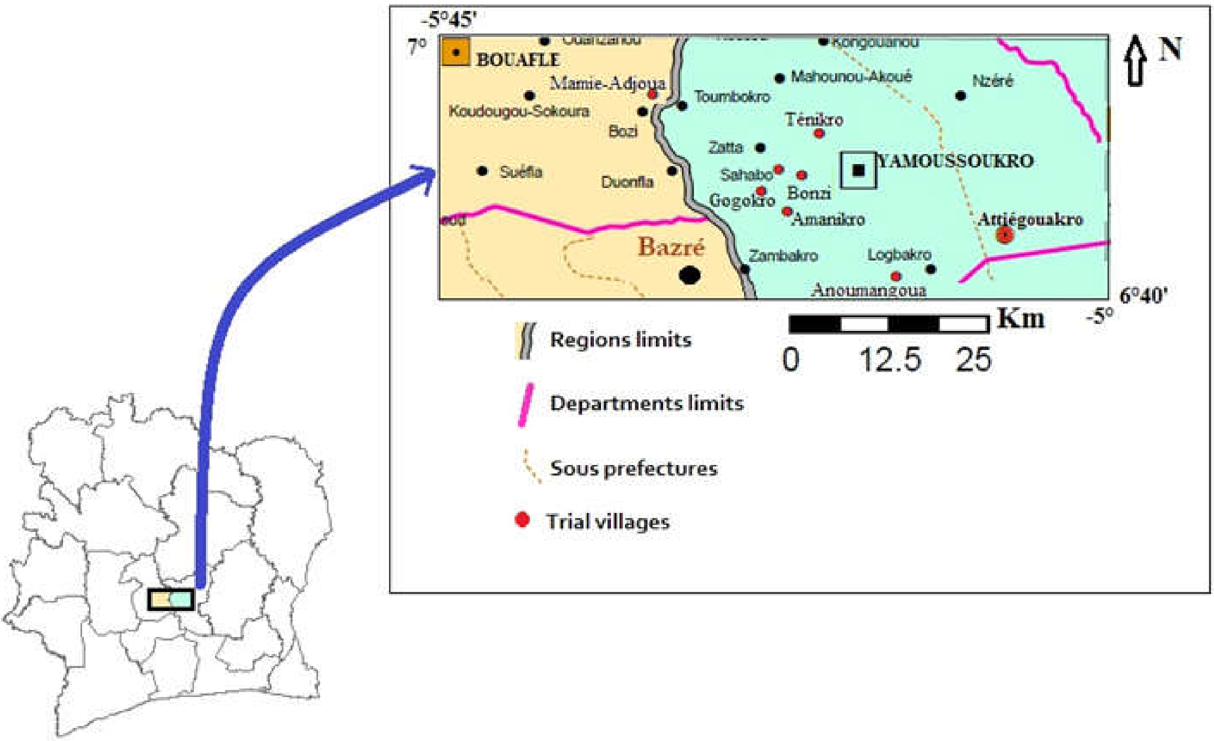



**Figure 1. Research area localization**

## MATERIAL AND METHODS

### Cocoa-tree

The principal material of the study is the cocoa-tree. Plantations are small scale ones and the seed material is often taken directly from others plantations. This type of seeds called "semence tout venant" justifies that no particular variety is used for this trial. In these plantations, we meet various other fruit-bearing and food and woody species of interest for the producer.

### Technical material

***The technical material used is composed of:***

- painting with oil, to mark the cocoa-trees;
- graduated ribbon of 50 m for the delimitation of the plots;
- plastic labels to differentiate the plots;
- shovel and pickaxe, machete, knife, journal sheets, plastic bags, and drill for the soil morphopedologic study ;
- GPS Garmin 12, for the catch of the geographical contact;
- camera;
- questionnaire for the ethnobotanic investigation;
- laptop with various software (Excel 2010, R 2.8.0 and STATISTICA (version 7.1) to collect and to analyze data.

### Experimental design

The experimental design is an on farm trial dealing with 54 plantations distributed in 8 villages. DAF and controls plots are delimited by 15 m X 15 m (225 m²) or 30 m X 30 m (900 m²) (Figure 2). 40 plantations are at least 5 years old and are already in production. Both DAF and control plots are harvested for yields. Village constitutes the replicate.

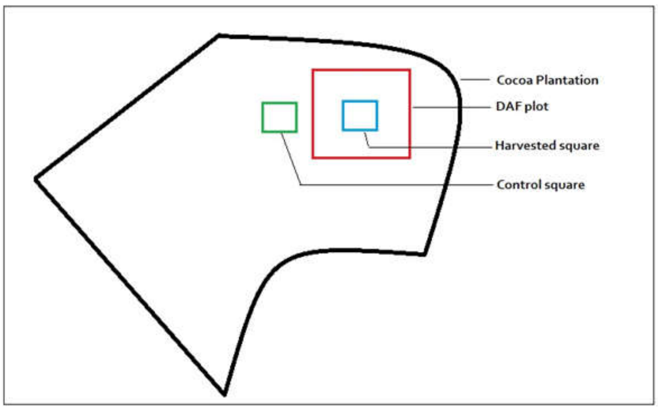



**Figure 2. Experimental design**

### Data collect

The variables measured, as well on the DAF as on control plots are relating to:

- The portfolio of the plant species and their uses,
- physicochemical properties of the soil,
- The productivity of the cocoa-trees.

The data measured during each harvest intended for the output are:

- The number of dent collected, healthy, attacks of brown rot or mirides,
- The mass of dent collected and healthy,
- And fresh and dry broad beans masses

### Soil morphology

For the morphological characterization of the soil profiles, 30 plots were used, namely, 16 in Lakes and 14 in Marahoué. 30 profiles were described and 30 samples were collected for chemical analysis. Soil color was observed using the Munsell soil color chart. Texture was evaluated using standard observation. The nature of the coarse elements (ferruginous concretions, quartz gravels and stones) was given by simple observation; their ponderal rate was estimated according to the Munsell soil color chart The internal drainage was appreciated based on the color. During surveys, soil depth was measured. Porosity was determined by the presence or the absence of pores in the profile. The biological activity was determined by the presence of roots, larvae of insects or insects in the horizons. The structure is observed by aggregates observations. During this process, soil samples are taken regularly, dried, preserved in plastic bags and send to the laboratory for physicochemical analyses.

### Soil analysis

The analyses are made according to the following procedures:

- Soil ph is measured with a ph-meter (potentiometer). It is the electrometric method (LANO, 2008);
- Organic carbon (C) determined by using Walkley and Black method (LANO, 2008);
- Nitrogen is carried out according to Kjeldahl method (LANO, 2008);
- Total and assimilable phosphorus is measured by the modified method of Olsen (LANO, 2008);
- Exchangeable bases ($K^+$, $Mg^{2+}$, $Ca^{2+}$ and $Na^+$) are extracted simultaneously from the soil with an ammonium acetate solution with neutral ph (LANO, 2008);
- CEC or cation exchange capacity is determined by the method of Metson (LANO, 2008).

### Statistical analysis

The index of diversity of Shannon (Magurran, 1988) was calculated to determine the specific diversity of the plant species. The formula of computation of this index is (Equation 1):

$$H' = - \Sigma (pi \ln pi) \quad \ldots\ldots\ldots\ldots(1)$$

Where:

- H' is the Shannon index of biodiversity
- $p_i$ proportion of a species per report with the full number of species in the study area (or specific wealth of the zone).

$P_i$ is calculated in the following way (Equation 2)

$pi = ni / N$ ……………(2)

Where:

- $n_i$ is the number of individuals for the species
- N is the total staff complement.

An analysis of variance (ANOVA) was carried out to compare the averages of the variables (soil, cocoa-tree productivity and agro-biodiversity) between the two plot types (DAF and control) of the same cocoa-plantations, and between various cocoa-plantations in the area.

## RESULTS AND DISCUSSION

### Agrobiodiversity

During ethnobotanic survey, 52 species belonging to 27 families were listed. The representativeness of these species per family is different. The most representatives' species contributing at 44,34 % to the area's agrobiodiversity belong to five principal families (Figure 3): Moraceae (11.54%); Euphorbiaceae (9.62%); Fabaceae (9.62%); Malvaceae (7.69%) and Anacardiaceae (5.77%). Seven families (Combretaceae, Meliaceae, Rutaceae, Sapindaceae, Solanaceae, Sterculiaceae and Rubiaceae) of which, each one represent almost 3.8 % of the diversity of the study area, cumulate 26,88 % of this diversity. Fifteen others families are represented by only one specy equivalent to 28,78% of the vegetative cover of the cocoa-plantations of the zone of study.

- Antiaris (24.97%), Ficus (19.95%), Musa (6, 47%) and Solanum (4.75%) in pieces DAF
- Citrus (25.33%), Musa (18.34%), Xanthosoma (9.17%), and Garcinia (8.30%) in the pilot pieces.

Only Ficus, Antiaris and Musa are seen both in DAF and Control plots with 46 species in DAF plots. The Shannon diversity index calculated is larger in DAF (2,20±0,71) than in the control plots (0,89±0,97) confirming more agrobiodiversity in DAF plots.

Cocoa cultivation associates various species to cocoa-tree. Those species can be saved when bushing or planted by the farmer. Species met in the cocoa-plantations have various uses. The most important uses are (certain species being multi-purpose): food (20 species), catering wood (33 species), monetary profitability (26 species) and traditional medicine (37 species). The multiplicity of these uses militates in favor of rapid adoption of such a production system.

### Morphological characteristics of the oil

Soil of the study area is in general deep (more than 1.2 m), except atypical zones where the presence of coarse elements restricts soil depth (Figure 4) with more than 50%. The rate of coarse elements in the surface horizons (0 to 22/32 cm) is lower than 10 %.

The texture of this horizon varies from gley-sandy to sandy. These soils generally gley-sandy, porous and well drained with a massive presence of invertebrates in the first 40 centimeters, which confers on this part of the ground, a leaky structure. In the plots close to valleys, we often note traces of hydromorphy. These deep soils with good drainage and gley texture could contain a good base of nutritive elements to support a good growth and an acceptable production of cocoa-trees. The surface horizon on average thick from 25 to 35 cm and rich in organic matter shelters most of feeder roots of the cocoa-trees.

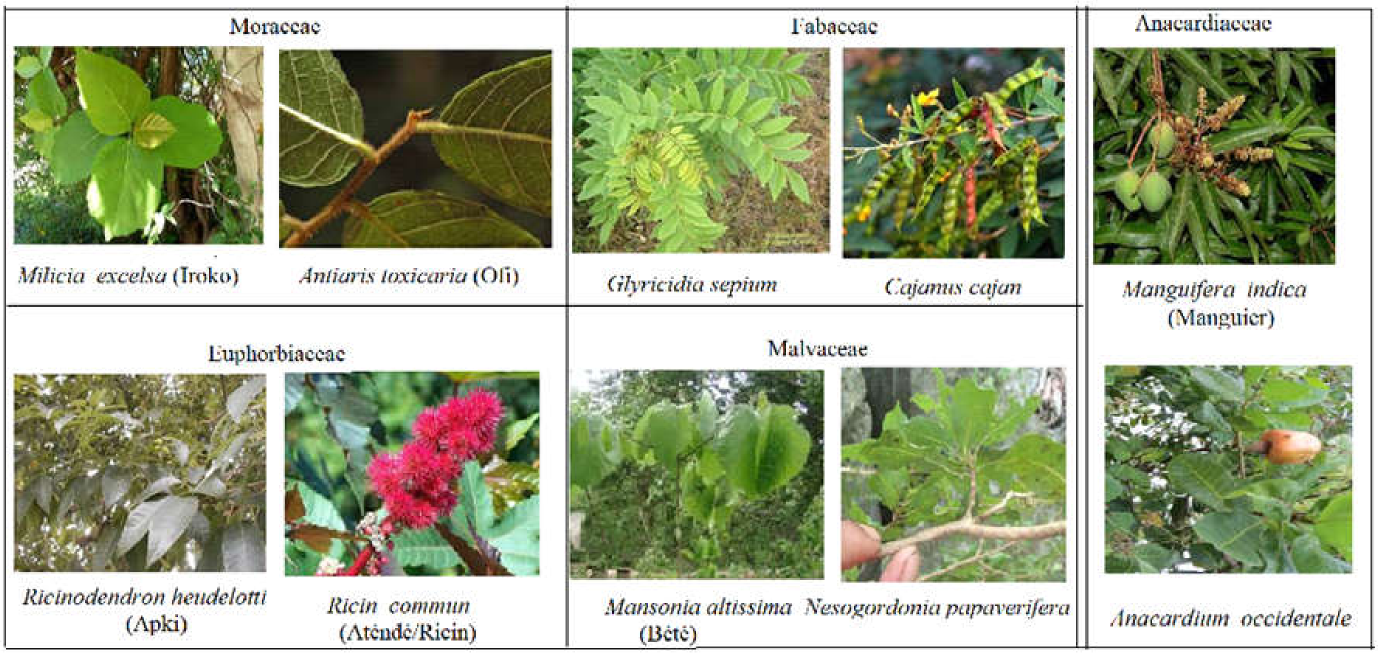
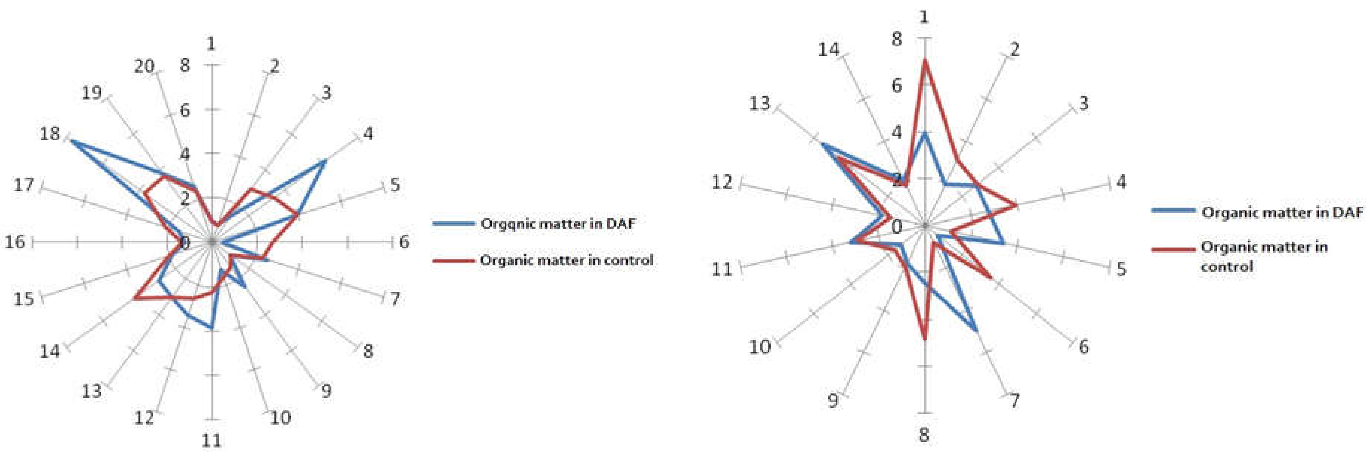



**Figure 3. Mean representative families in Cocoa plantation in Central Cote dIvoire**

**Figure 4. Some soil profiles in Yamoussoukro and Bouafle**




a b

**Figure 5. Soil organic matter content (a) Yamoussoukro and (b) Bouaflé**

**Organic matters (MO) and nitrogen**

The percentages of organic carbon and nitrogen and the associated parameters that are the organic matter rate and the carbon/nitrogen ratio (C/N) vary from a plot to another. Variability between DAF plots and control is randomly done and none of these two systems 4 presents a better situation, no statistical difference has been observed. However, the OM content averages in DAF plots (2,6%) are very weakly higher in general and with no significant difference of that of control plots (2,37 %) (Figure 5). Certain control plots show more important OM rates where the cocoa-trees are youngest. These high organic matter values are in favor of a good aptitude of the cocoa plantations to provide the fresh organic matter to the soil.

The soil of Amanikro, with low OM contents (0,93% in DAF and 0,86% in control), appears as the least provider of organic matters and present the greatest limitations to the productivity. This level could be explained by the youth of the plantations. Soil pH (6 to 6.90) is very close to neutrality as well on DAF as on control plots. These levels of pH associated with good OM levels let predict good biological activity and subsequent good nitrogen content. Indeed, a strong correlation is established between the organic matter rate and the nitrogen content with correlation coefficients of 0.96 and 0.97 respectively in Lakes and Marahoué (Figure 6). These values mean good mineralization level of the OM in the cocoa plantations. Organic matter content of the cocoa plantation varies from plot to plot as well in DAF or in control.

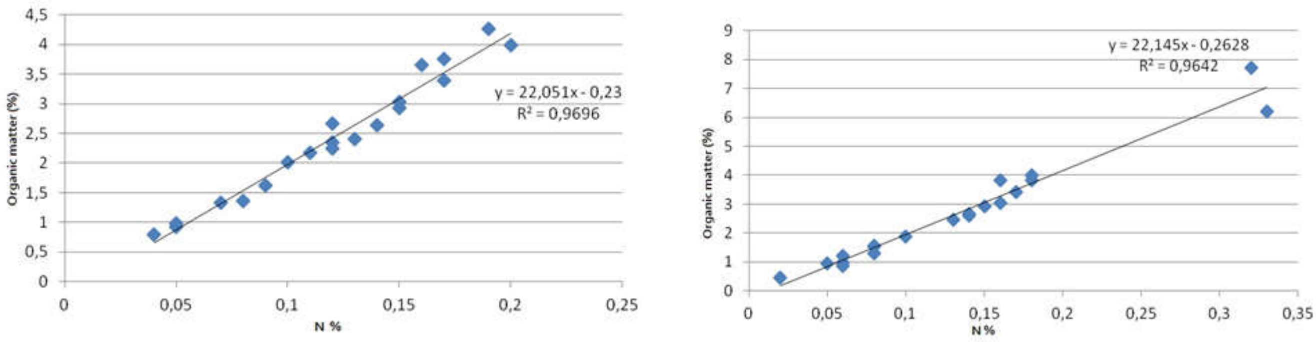



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**Figure 6. Correlation between organic matter and nitrogen content (a) Yamoussoukro and (b) Bouaflé**

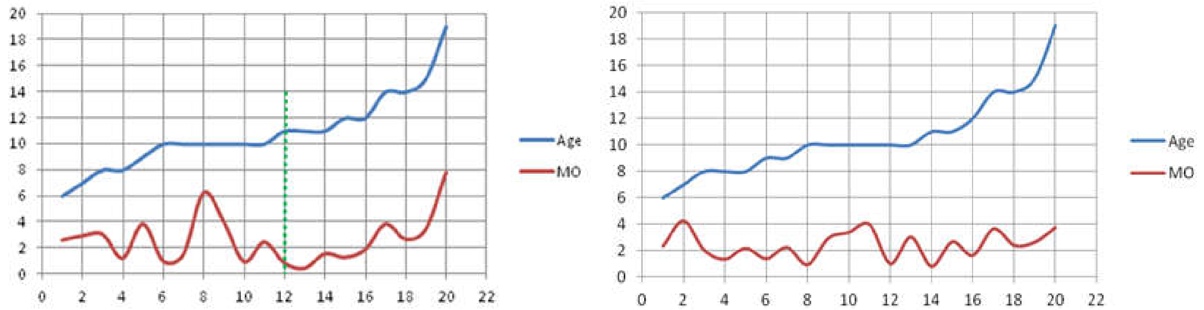


**Figure 6. Relation between organic matter production and plantation age**

This variation is irregular in the first ten years of the cocoa plantation implantation. Beyond the 12th year, the organic matter increases with time in DAF in opposite to the control (figure 7). Strong agro biodiversity in DAF can justifies this evolution. DAF practice started only one year ago and such duration is short to allow a clear improvement of the biological activity. If this practice continues, it could, in the long term improve the soil global fertility properties. The DAF system aims at improving the soil fertility by the improvement of the organic matter rate brought by the continuous presence of vegetation and the various pruning.

The measured CEC is different between DAF and control and within plots type (Table 1). In a general way, the potential fertility of DAF and control are similar except for Gogokro and Ténikro. Indeed, for this two villages, the soil chemical potential in controls (CEC=8,77 and CEC=9,85 for Gogokro and Ténikro respectively) constitutes severe limitation for soil productivity when this level is improved for DAF (CEC=15,19 and CEC=12,67 for Gogokro and Ténikro respectively) being of a moderate limitation. The average age of the plantations in this study is approximately 11.5 years, corresponding to the bottom limit for DAF to affect soil fertility and its productivity. However, the plantations of Ténikro and Gogokro are oldest (+ 16 years) and those of Attiégouakro youngest (6 years). It appears clearly that, more the plot is old, more it is potentially rich chemically and presents less constraints for cocoa tree productivity. These results are explained by the plots age. Indeed, plantations ages in Lakes regions vary of 6 with more than 16 years whereas those in Mamie-Adjoua (Marahoué) are younger.

**Table 1. Cations exchanges capacity**

| Villages | CEC DAF (cmol+.kg-1) | Limitation | CEC Control (cmol+.kg-1) | Limitation |
|---|---|---|---|---|
| Amanikro | 3,2 | 1 | 3,48 | 1 |
| Anoumangoua | 16,95 | 3 | 15,07 | 3 |
| Attiegouakro | 6,27 | 2 | 7,13 | 2 |
| Bonzi | 7 | 2 | 5,6 | 2 |
| Gogokro | 12,67 | 3 | 8,77 | 2 |
| Sahabo | 6,85 | 2 | 9,2 | 2 |
| Ténikro | 15,19 | 3 | 9,85 | 2 |
| Mamie-Adjoua | 15,6 | 3 | 15,69 | 3 |

Fertility limitation: 1- very severe, 2- severe, 3- moderate

## Nitrogen (N), Phosphorus (P) and Potassium (K)

The soil content in potassium of the zone of study varies from 0.03 to 0.06 cmol+.kg-1in DAF and from 0,04 to 0.07 cmol+.kg-1 for control (Table 2). These weak values show that potassium can constitute very severe constraint to cocoa productivity if production is made without fertilizer. The nitrogen content, varies from 0,06% (poor soil) to 0.21% (rich soil) on DAF and from 0,05% (poor soil) to 0.17% (rich soil) for control plots. With regard to phosphorus, total phosphorus varies from 258,5 $gkg^{-1}$ to 689 $gkg^{-1}$, when assimilable phosphorus varies from 23.75 to 63 $gkg^{-1}$. The soil is well provided in phosphorus in both regions and it does not constitute a constraint.

## Cocoa production

The mean of fruits per tree is more important in the control (11.64 fruits) than in DAF (10.61 fruits).

**Table 1. Soilcontent in N, P and K**

| Plots Id | DAF | | | Controls | | |
|---|---|---|---|---|---|---|
| | N (%) | Pass(ppm) | $K^+$ (cmol+/kg) | N (%) | Pass(ppm) | $K^+$ (cmol+/kg) |
| AM24 | 0,06 | 26 | 0,048 | 0,05 | 22 | 0,033 |
| AM25 | 0,06 | 23 | 0,038 | 0,04 | 16 | 0,046 |
| AN35 | 0,08 | 29 | 0,033 | 0,15 | 26 | 0,028 |
| AN5 | 0,33 | 43 | 0,035 | 0,17 | 41 | 0,089 |
| AN6 | 0,18 | 56 | 0,092 | 0,2 | 44 | 0,049 |
| AT17 | 0,02 | 27 | 0,022 | 0,12 | 49 | 0,031 |
| AT3 | 0,14 | 34 | 0,04 | 0,12 | 22 | 0,046 |
| AT30 | 0,05 | 34 | 0,026 | 0,05 | 66 | 0,036 |
| B23 | 0,13 | 39 | 0,045 | 0,08 | 48 | 0,047 |
| B35 | 0,08 | 29 | 0,066 | 0,09 | 34 | 0,046 |
| G154 | 0,18 | 26 | 0,1 | 0,12 | 25 | 0,098 |
| G26 | 0,17 | 29 | 0,046 | 0,14 | 24 | 0,088 |
| G64 | 0,16 | 34 | 0,026 | 0,15 | 22 | 0,03 |
| S10 | 0,15 | 25 | 0,048 | 0,19 | 44 | 0,098 |
| S12 | 0,1 | 28 | 0,084 | 0,1 | 22 | 0,065 |
| S61 | 0,06 | 18 | 0,066 | 0,07 | 23 | 0,03 |
| S68 | 0,08 | 24 | 0,028 | 0,11 | 22 | 0,033 |
| T2 | 0,32 | 63 | 0,056 | 0,17 | 41 | 0,055 |
| T25 | 0,16 | 44 | 0,077 | 0,16 | 28 | 0,044 |
| T47 | 0,14 | 21 | 0,025 | 0,13 | 77 | 0,033 |

**Table 2. Cocoa tree yield**

| Villages | Yield in kg per plant | |
|---|---|---|
| | DAF | Control |
| Amanikro | 0,95 | 1,19 |
| Anoumangoua | 1,06 | 0,91 |
| Attiegouakro | 0,8 | 0,55 |
| Bonzi | 0,96 | 0,75 |
| Gogokro | 2,97 | 0,93 |
| Sahabo | 1,49 | 1,74 |
| Ténikro | 0,53 | 0,62 |

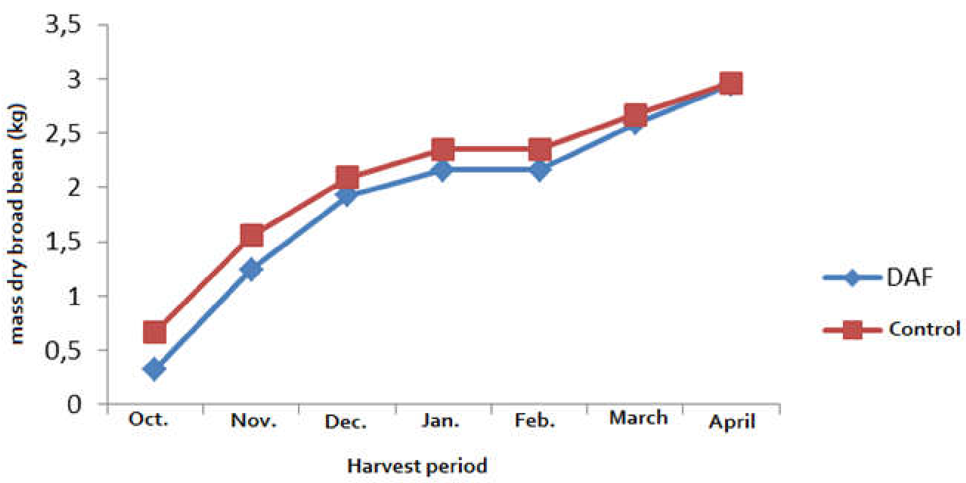


**Figure 7. Cocoa tree yield evolution fro; October to April**

In addition to that, the most productive cocoa-tree in control is encounter in Sahabo (17.06 fruits), with (14.18 fruits) for DAF in Sahabo. In opposite, DAF gives better mass fruits 4.45 kg (DAF) and 4.18 kg (control) and broad beans 1.25 and 0.96 kg per tree compare to control (Table 3). Cocoa yield is more important in DAF (633.15 kg.ha-1) than in the witnesses control (569.71 kg.ha-1). In addition, these outputs prove to be close to the theoretical yields in the two types of plantations and all the villages. Actually, DAF practice has a significant effect on the cocoa-tree productivity. Evolution of the cocoa production. The harvest of the cocoa starts in October and increases regularly up to January. No harvest has been made in February. March and April correspond to the little production period where few product is collected. Controls' broad beans mass is higher than DAF production at harvest beginning and progressively, DAF and control end at the same level approximately 3 kg.ha$^{-1}$ (Figure 8).

## DISCUSSION

### Impacts of DAF system on soil fertility

Various species belonging to 27 botanical families were identified showing the specific resources of the zone. This agrobiodiversity leads, according to Sonké (1998), to good environmental conditions for DAF system introduction in the area. This is confirmed by the development of certain forest resources which were saved by the farmers during the creation of the plantations and selective cleaning. This practice meets the need for the farmers to satisfy various needs as indicated by FiBL, (2011). Indeed, all plants kept in the plantation contribute to shades that protect the young cocoa-trees, providing the subsistence or having ever an economic or medicinal impact for the farmer. These functions are primarily reserved to the forest species, that importance in a forest-savanna transition zone, appears to be secondary in comparison with the place occupied by the fruit-bearing and food species (Jagoret *et al.,* 2012). Consequently, this system has enough chance for rapid adoption because of its large scale of interests (Soro *et al.,* 2010). The Shannon index value (2,34) of DAF system in cocoa plantation created in the zone of study is close to the values obtained in the same conditions in Nigeria 2,7 (Oke *et al.,* 2007) and 2,6 in Ghana (Asase and Tetteh 2010). This index remains however lower than that observed in the forest zone in central Cameroon; 3,4 in Likié department and 3,8 in the Nyong and So' O areas (Messiah 2007). These differences could be related to the age of the plots which is less than one year and principally to the climatic zone. Surely, Milz (2012) showed that our one year observation still too short to allow a good development of plants and variability in species. The persistence of vegetation and especially species selection contributes to an improvement of the soil physical and chemical properties. The improvement of soil organic matter contents noted in DAF plots is due mainly to the continuous presence of vegetation which, by the fall of the leaves and pruning, constitutes a durable source of contribution of litter on the ground. Beer *et al.,* (1998), studied this phenomenon in the agro-forests of Central America, and evaluated the litter on the soil to 14 t/ha/year, corresponding to a nitrogen contribution of about 340 kg N/ha/an. The age of the plot constitutes a factor favorable to organic matter production in the cocoa plantations. This result allows to consider the renewal of the old plantations of cocoa-trees by progressive destruction after having plant young cocoa-trees which will develop quickly with the benefit of shade and favorable global soil properties. The DAF system has advantages when implanted in old cocoa-plantations of more than 12 years. However, its effect is not immediate and would require several years of establishment before show effect if started at the installation of the cocoa plantation.

### Impacts of DAF system on the productivity of the cocoa-tree

The dry broad bean yields recorded during the six months that lasted the study give an average of 633,2 kg.ha$^{-1}$ in DAF and 586,0 kg.ha$^{-1}$ in control. These two results are not statistically different. The short duration of our DAF application justifies those weak yields. However these yields are higher than those obtained during former studies carried out in Côte d'Ivoire that gave 260 to 560 kg.ha$^{-1}$ in the old system (Assiri *et al.,* 2009) and can be improved in the medium or long term. Another justification of those results is that, DAF plots are modifications of part of the traditional system plot. The study uses plantations of different ages and different cocoa varieties that are not improved. That can be a reason why the differences are not significant. Indeed, the age of the plantations is regarded as being a key factor on the yield of the cocoa-tree, according to studies carried out by Jagoret *et al.,*, (2012) and Smoot *et al.,*, (2013). These studies showed that the yield of the DAF is high in the interval of age from 21 to 25 years. These factors are at the origin of the similarity between the given productivity parameters (dents quantity, fresh and dry broad beans and yield) on the two types of cocoa-plantations (DAF and control). We can invite the farmers to apply DAF system to regenerate the old and not very productive plantations while we continue trials to precise the DAF system potentialities.

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