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Structural And Functional Characteristics Of Cocoa Agroforestry Systems In Côte d'Ivoire

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Abstract

Agroforestry is defined as the exploitation of land by the simultaneous or sequential combination of woody trees and crops or animals, with the aim of producing goods or services beneficial to humans. Therefore, in order to characterise the Ivorian cocoa orchard, a survey was carried out in the cocoa orchard of Côte d'Ivoire from 2014 to 2016 in 16 departments representative of the three main cocoa-producing areas. A sample of 474 plantations was surveyed. The aim of the study was to describe the structure and functioning of traditional agroforestry systems in the Ivorian orchard. The results revealed a low-density agroforestry system with an average of 10 to 30 trees/ha. This system does not correspond to any planting scheme. This system is also dominated by forest species. The trees in the orchard are generally residual species, either spontaneous or planted by the growers. Species introduced by growers are most often in the form of seeds and wildings. Several advantages of the presence of trees were mentioned by the producers, but the main one remains the provision of shade for the cocoa trees. However, the main disadvantage is that these trees can be a source of disease and pests for cocoa trees. This study has shed light on the composition, structure and functioning of traditional agroforestry systems in the Ivorian cocoa orchard. All this information will contribute to the creation of efficient modern agroforestry systems for sustainable cocoa production.

Key words: *agroforestry, characteristics, cocoa, Côte d'Ivoire, survey,*

INTRODUCTION

Agroforestry refers to all agrosystems where trees, crops, and sometimes animals, are combined in ecosystem ways such as biodiversity conservation and enhancement, soil health, resource efficiency (Zhang et al., 2018) and carbon sequestration. It therefore offers an opportunity to diversify and maintain production with the aim of improving social, economic and environmental conditions for all those who work the land (AFAF, 2014). Agroforestry is neither a recent trend nor an innovative farming method (Torquebiau et al., 2002). Rather, it is one of the oldest agricultural production methods. However, it was sidelined for a period due to the growth of modern agriculture (Nair, 2007). Agroforestry systems are widespread throughout the world, particularly in humid tropical zones (agroforests based on cocoa and coffee trees, etc.), temperate zones (orchard meadows, silvo-arable systems based on annual crops, etc.) and Mediterranean zones (intercropping with olive groves, wooded rangelands, etc.). This cropping system is a solution for the sustainability of cocoa production in Côte d'Ivoire, which has developed at the expense of forest reserves. This deforestation has made a major contribution to the climatic imbalances observed (Redd +, 2017), mainly affecting agriculture and the environment in general. In this context, the conservation of essential plant species has become a priority for rural communities (Koulibaly *et al.*, 2010; Piba *et al.*, 2011) as a means of adapting to climate change. The increased interest in agroforestry practices among farmers observed recently is in line with this trend. However, according to a number of observations and reports, traditional cocoa-based agroforestry systems exist in the orchards of Côte d'Ivoire. With this in mind, this study was carried out with the aim of characterising the cocoa-growing system in Côte d'Ivoire, characterising existing cocoa-growing systems in Côte d'Ivoire and establishing a typology of these systems.

The analysis resulting from this characterisation is intended to guide the development of modern, more efficient agroforestry models that can be offered to growers as sustainable alternatives.

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METHODOLOGY

Study area

The survey was carried out in sixteen (16) departments representative of the southern forest half of Côte d'Ivoire, which is the cocoa production zone, covering 103 sub-prefectures, villages and camps. The area has a sub-equatorial, bimodal climate, with average rainfall of between 1,200 and 1,700 mm per year. Average annual temperatures range from 24 to 32°C (Kouamé et al., 2007). Most of the soils are ferralitic (Perraud, 1971).

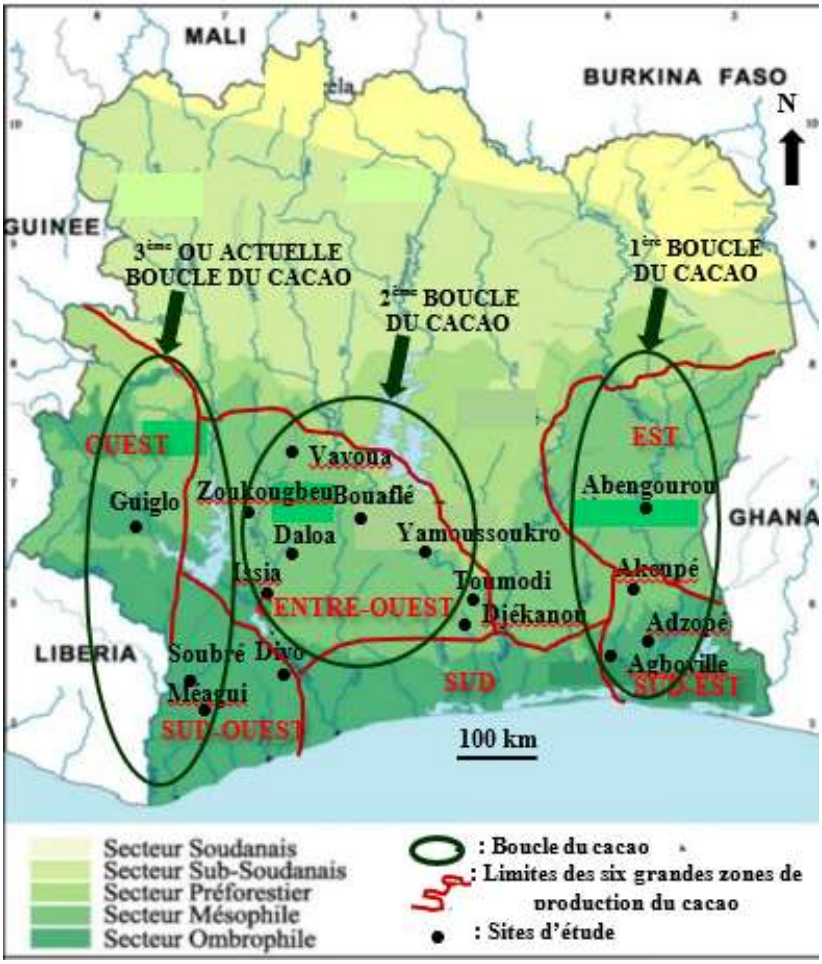

Figure 1.

Table 1. Presentation of survey sites

Cocoa-growing areas	Regions	Departments	Survey sites (Sub-prefecture, Villages and Camps)	Number of plantations / Producers surveyed	Total area of cocoa plantations (Ha)
1st loop	Indénié-djuablin	Abengourou	Akoikro (N'zebenou), Amelekia, Arifi, Kodjinan, Kouassibeniekro, Niable (Adoninkro, Affalikro, Assokro, Anuanuan, Anuansuê), Yakassé Feyassé (Eboissue, Sankadiokro), Konankro.	76	342,5
	Mé	Adzopé	Agou (N'guessankoi), Ahuikoi, Biasso, Nehanzin.	16	47
		Akoupé	N'koupé, Grand Yapo, Boka Oho, Offoumpo.	8	18

	Agnéby-Tiassa	Agboville	Petit Yapo, Grand Morié, Grand Yapo, Offa.	16	53,25
Total	3	4	28	116	461,15
2nd loop	Bélier	Djékanou	Albertn'dakro, Djetran-Yaokro, Kocoubo, Mougnan, Wobekro.	14	26,5
		Toumodi	Assouvoue, Bofledo, Lahourebo, N'doukahakro.	23	75,5
	Haut Sassandra	Daloa	Bohoua-Bahouan, Bohouahawa, Carrefou Pk 12, Gboguhé (Keibla), M'bayakoffikro, Tapeguhé.	35	94,25
		Vavoua	Vavoua, Bonoufla.	11	25
		Issia	Boguédia (Mimia1, Mimia2, Mimia3), Issia, Iboguhé, Madrassokouro, Mandiassoucloi, Tetia.	32	77,5
		Zoukougbeu	Gregbeu (Blaikro), Guessabo (Ouatigbeu, Gorodi, Dagbrezou).	17	40,25
	Lac	Yamoussoukro	Kossou (Angosse, Yobouekro), Senan.	15	81,5
	Marahoué	Bouaflé	Benou, Bledi, Bonon (Djahakro, Saa, N'guessankro, Bokrolaye), Bozy, Garango, Koupela, Lopouafla, Pakouafla, Pakouabo, Sokrolaye, Tingodogo.	33	84,25
Total	4	8	51	180	504,75
3rd loop	Lôh-Djiboua Nawa	Divo	Bradodougou, Konankro, Pétimpé, Yobouékro, Boubo, Data, Tablédjou, Didoko, Hiré, Hiré (Boakako, Kagbé), Ogoudou (Kouamékro).	115	484
		Méagui	Méagui	4	7
	Nawa	Soubré	Alloukro, Kouadiokro, Négréagui, Oupoyo, Campement Loua-paul, Norbert Carrefour.	35	84,25
	Cavally	Guiglo	Bloc Gnéo, Bloc Katy, Kridy, Mambly.	24	45,57
Total	3	4	24	178	620,82
Total général		16	103	474	

METHODS

Sampling and surveys: The study was based on a cross-sectional survey carried out in 16 departments of Côte d'Ivoire that are representative of the southern forest zone, a cocoa-producing area, i.e. 103 sub-

prefectures, villages and camps. A pre-survey phase was carried out beforehand, in a few villages along the Divo-Tiassalé axis, on around twenty households. The aim of this stage was to test, adjust and adapt the questionnaire to the level of understanding of the producers, most of whom did not attend school. The actual surveys were carried out with 474 farmers (Table 1). The interviews were conducted directly on the cocoa plots, in order to combine the collection of socio-economic data with a botanical survey. The information gathered from the farmers concerned the characteristics of their cocoa farm (surface area, seed used, production, type of maintenance, etc.) and their level of knowledge of the trees observed in the cocoa farm (importance, name of the trees, period of introduction, etc.). In addition, a herbarium was compiled from plant species other than cocoa observed in the plantations. The species collected in the herbarium were identified at the Université Jean Lorougnon Guédé and at the Centre National de Floristique (CNF) of the Université Félix Houphouët Boigny.

Description of the questionnaire and data collected

The structured questionnaire, applying both qualitative and quantitative methods of data collection and analysis, served as the survey document. The designed questionnaire was organised in four parts with multiple choice answers. The first part concerns general information about the producer (village, sub-prefecture, name, age, ethnic group, level of education, etc.). The second part consists of questions about the plantation (area, density, location, year established, previous crop, type of cocoa seed, annual production, etc.). The third part concerns information on the trees associated with cocoa trees, in particular the origin of the tree, the planting system, the type of planting material, the name of the trees, the year in which they were planted, etc. The fourth part deals with the management and ownership of trees within the FAS (supervision of a structure for the management of forest trees, effect of the presence of trees on the cocoa tree, producers' preferences, difficulties in exploiting trees, etc.).

Statistical analysis

All the data collected were processed and analysed using Excel. Several analyses of variance were performed on the quantitative data using SPSS version 22 software. In order to compare the characteristics of the cocoa farms, an analysis of variance was carried out with SAS software using the Bonferroni test (Dunnet) for variables such as crop precedent, yield and age of cocoa farms, density and period of introduction of associated trees in the cocoa farms and the mode of use of plant species, etc. The analysis of variance was performed using the Bonferroni test (Dunnet).

RESULTS

Presence of multi-purpose cocoa-tree associations

Figure 1 shows the percentage of trees in cocoa plantations. It shows that 95.53% of the cocoa plantations explored are associated with plant species.

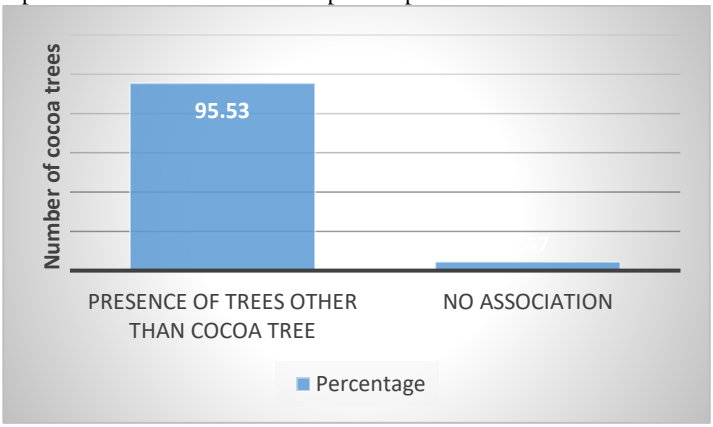

Fig. 1. Percentage of cocoa farms with or without associated trees

Importance of associations between cocoa trees and other plant species

Figure 2 shows that 79.95% of the plant species associated with cocoa trees are of significant value to producers, particularly for timber production, consumption, medicinal uses, fertilisation, shade and income generation. On the other hand, 18.05% of producers do not consider them to be of any use, while 2% say they are unaware of their potential usefulness.

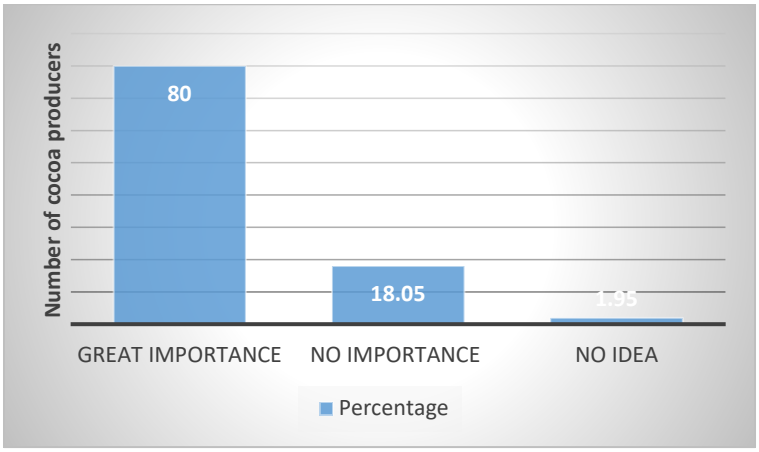

Fig. 2. Importance of trees associated with cocoa trees

Spatial organisation of associated species in cocoa plantations

The majority of associated species (94.07 %) are scattered throughout the cocoa plantations and their distribution in the orchards does not follow any specific planting system. Only 5.93 % of the cocoa farms encountered have species (legumes) that respect a 20 m x 20 m layout (figure 3).

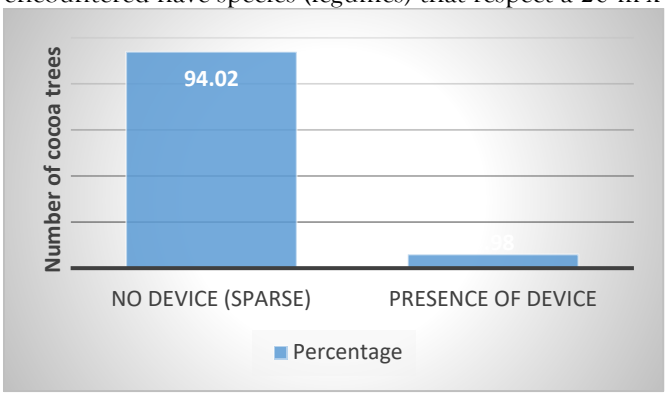

Fig. 3. Existence of association planting systems

Types of tree associated with cocoa trees

According to the figure, 85.5 % of the trees associated with cocoa trees are forest species. Fruit species represent 14.5 % of all associated trees.

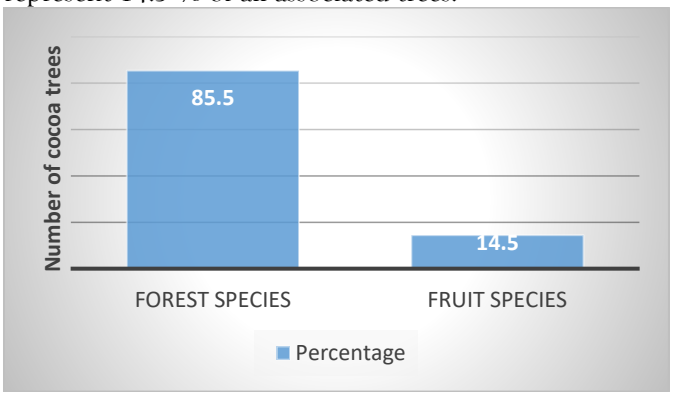

Fig. 4. Types of tree associated with cocoa trees

Origin of the associated trees. Tree species associated with cocoa trees fall into three main categories according to how they were introduced. The majority correspond to trees voluntarily planted by producers (35.25 %) and residual species not felled during site preparation (32.52 %). There are also spontaneous species (28.53 %) made up of forest species that have grown naturally after the plantation has been established.

Plant material used. Five types of plant material were identified as sources of introduction of tree species into cocoa farms. However, seeds are the main method of introduction, accounting for 70% of cases. Wildings (21.12 %) are the second most important source of plant material for species associated with cocoa.

Tree introduction period. According to Figure 7, plant species are mostly associated with the young age of the cocoa plantation, i.e. between 0 and 5 years (62.85%). Late introduction, i.e. between the ages of 16 and over 30, remains marginal (0.85-0.33 %).

Management. Practically 50 % of the population said that they received no guidance, but that their knowledge and practice of agroforestry came from themselves (49 %) and 33% received support from family or friends.

Table 2. Producer responses according to the questions asked

	Average
Origin of associated trees	
Residuals	32.52 a
Spontaneous	28.53 a
Planted by the producer	35.25 a
Other origins	3.69 b
Plant material used	
Sauvageons	21.12 b
Seeds	70.79 a
Cuttings	5.84 c
Marcottes	0.22 c
Grafts	0.45 c
Other	1.57 c
Period of tree introduction (years)	
]0-5] Young plot	62.85 a
]5-10] Young plot	9.12 b
]11-15] Adult plantation	4.81 b
]16-20] Adult plantation	0.83 c
]21-30] Adult plantation	0.66 c
]30-Plus] Senescent plantation	0.33 c
Structure d'encadrement	
Parents/Freinds	33.26 b
SATMACI	1.77 c
CNRA	1.55 c
ANADER	1.64 ab
certification Program	1.77 c
Personal	49 a

Density of association. In more than 77.95 % of the orchards visited, an average of 10 to 30 tree species are associated with one hectare of cocoa trees. Around 12 % of cocoa farms have between 30 and 50 trees.

Advantages of the cocoa/tree association. Associated trees offer various advantages, the main one being the provision of permanent shade (39 %). In addition, these trees also help to retain soil moisture (20 %) and improve cocoa productivity (16 %).

Disadvantages of the cocoa/tree association. The results presented in Figure 10 highlight certain disadvantages linked to the association of cocoa trees with other tree species, as perceived by producers. The main disadvantage of trees associated with cocoa trees is that they can be sources of disease and harbour pests (27.82 %) that are harmful to cocoa trees. In addition, these trees can compete with cocoa trees for water (16.94 %) and contribute to drops in production (14 %).

Table 3. Producer responses according to the questions asked

	Average
Tree density class / ha	
]0-10]	35.12 a
]10-30]	42.83 a
]30-50]	11.99 b
]50-100]	6.42 b
]100- more]	3.64 b

Advantages of associated trees	
Reducing weed cover	2.80 c
Good production	16.03 b
Soil moisture	20.48 b
Good health of cocoa trees	3.44 c
Improving soil fertility	11.70 b
Shade power of attorney	38.68 a
Other benefits	6.87 c
Disadvantages of associated trees	
Water competition	16.94 b
Source of disease and pests	27.82 a
Decline in production	14.74 b
Falling damage to cocoa trees	13.64 b
Poor cocoa tree development	12.81 b
Soil impoverishment	9.78 b
Other disadvantage	4.27 c

Use of trees in cocoa farms. The results in the figure show that trees associated with cocoa trees have multiple uses. In fact, 26 forest species and 5 fruit trees have been identified as shade trees for cocoa. Twenty-four forest species and 9 fruit species are used for medicinal purposes by growers. In addition, 19 forest species are used as timber. Finally, several other species are used for food purposes, some to demarcate fields, others as fertilisers and for spiritual reasons (Fig. 5).

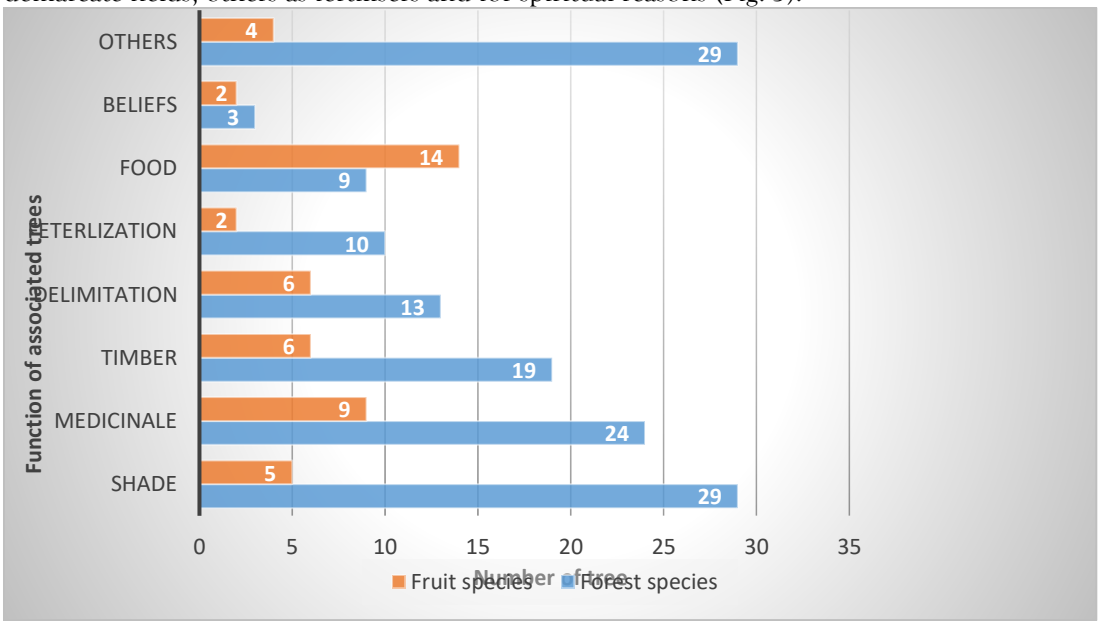

Fig. 5. Functional Roles of Associated Tree Species in Cocoa Agroforestry

Statistical analysis

The data was coded to make it easier to use, then entered into EXCEL. One-dimensional descriptive statistics methods were used to calculate relative frequencies, proportions, histograms, arithmetic means, variances, standard deviations and coefficients of variation. In order to compare cocoa farms with each other for each variable according to production zones. Analyses of variance were performed at the 5% threshold with SAS software version 9.2 (SAS Institut, 2009), using the bonferroni test (Dunnet).

DISCUSSION

Agroforestry is seen as a solution for the long-term sustainability of the cocoa sector and national efforts to restore forest cover in Côte d'Ivoire. However, it is important to carry out a diagnosis of the orchard in order to determine the characteristics of an existing traditional agroforestry system. To this end, a survey was carried out in the Ivorian cocoa orchard. The results obtained during the survey generally show the existence of a traditional agroforestry system in the Ivorian orchard. In the majority of cocoa farms visited during the survey, agroforestry systems, i.e. trees other than cocoa, which are as different as one another, exist in the cocoa orchard in Côte d'Ivoire. These agroforestry systems are very sparse and fairly light,

which means that they are hardly noticeable and give the impression that they do not exist. Our results are in agreement with Viswanath *et al* (2018) who mentioned that traditional agroforestry systems can be described as a set of ancient agroforestry systems practiced worldwide with varied structure, function, socio-economic attributes and ecological services. They are found all over the world, mainly in the tropical, subtropical and even temperate regions of Asia, Africa, Europe, North America, South America and the Pacific islands, although they are less well studied scientifically. In addition, the majority of farmers (79.95 %) stated that the species present in cocoa farms are of great importance to them because they provide several goods and services, including timber, consumption, medicinal services, fertilisation, shade and a source of income. According to several authors, agroforestry systems offer a number of advantages. From an environmental point of view, agroforestry allows better use of groundwater, which is essential for maintaining the water table and for sustainable water use. Agroforestry reduces the leaching of nutrients into neighbouring bodies of water. Agroforestry also reduces soil erosion on farms, helping to preserve their health and structure. From an economic point of view, agroforestry systems can offer farmers various sources of income. Trees are a valuable resource, and farmers can harvest and sell products such as timber, firewood, fruit and so on. In addition, healthier soils avoid excessive use of pesticides and fertilisers, thereby reducing input costs (Sullivan *et al.*, 1992; Rasul & Thapa, 2006; Bijarpas *et al.*, 2015; Murthy *et al.*, 2016). However, very few producers do not consider this to be important. In the orchard, the majority of species associated with cocoa trees do not follow any particular planting system and are scattered throughout the orchards. The results obtained are in line with those of Okullo (2003) who observed that most of the tree and shrub species associated with cocoa trees were arranged randomly and grew naturally on the plot. However, only 5% of cocoa trees have planting arrangements (20 x 20 m) for glyricidia planting. These are actually trial plots that were set up several years ago by research bodies (CIRAD, ICRAF, CNRA, etc.) and were offered and advised to growers as part of trials to improve fallows with legumes (Assiri *et al.*, 2006). These plots are generally found in the eastern region of Côte d'Ivoire. In most of the plots encountered during the survey, forest species (85 %) are largely associated with cocoa trees, while only 15 % contain fruit species. These results are contrary to those obtained by de Oke & Okebiyi (2007) during their work in 3 major cocoa-producing regions of Ondo State. On the other hand, they showed that the trees found in cocoa plantations were edible fruit trees. The survey also revealed that 35 % of plant species are planted by producers, 32 % are residual plant species and 28 % are spontaneous plant species. The high proportion of forest species observed in cocoa plantations may be due to the fact that these are residual species left over from the preparation of plantations before the cocoa trees were planted or that grow spontaneously in the cocoa trees. Fruit species are generally planted by farmers in the empty spaces of cocoa plantations for their own consumption or to sell the products obtained. The majority of species introduced into cocoa plots (62.85 %) are introduced when the cocoa is young, i.e. between 0 and 5 years old. However, late introductions are used to fill gaps in the plot following cocoa tree mortality. Plant species are introduced into cocoa farms largely in the form of seeds that producers sow (35.25 %) and in the form of wildings (21%). Cocoa plantations are dominated by low densities of plant species ranging from 10 to 30 trees/ha, whereas in Central America, specifically in Panama, Costa Rica, Nicaragua, Honduras and Guatemala, high densities of association of plant species with the cocoa tree are observed, up to 200 trees/ha (Rolando *et al.*, 2013). Several advantages and disadvantages of agroforestry were mentioned by growers. However, the major advantage of species associated with cocoa trees is the provision of shade (38.68 %), while the major disadvantage (27.82 %) is that these species can be sources of disease and nests of insects and pests of the cocoa tree. The shade provided by the associated trees is used for shelling, resting and protecting young cocoa trees from the sometimes excessive sunlight. Several authors have also identified a number of advantages and disadvantages of agroforestry. From an environmental point of view, better use of groundwater is essential to maintaining the water table and ensuring the sustainable use of water. In addition, agroforestry reduces the leaching of nutrients into neighbouring water bodies. Agroforestry also reduces soil erosion on farms, helping to preserve their health and structure. In addition, in agroforestry systems, trees are a valuable resource that can be used for self-consumption and a source of additional income for producers (Jagoret *et al.*, 2014; Notaro *et al.*, 2019). As disadvantages, the authors mentioned the possibility of a drop in crop production due to excessive shading that could limit light infiltration. Moreover, these trees can be breeding grounds for pests and diseases. In the same vein, Aka *et al* (2020) revealed that certain trees (cheese tree, kapok tree, iroko, baobab, mirabel tree, etc.) are harmful to cocoa trees because they are hosts or reservoirs of swollen

shoot. However, some authors have shown that the introduction of banana trees, as well as fruit and forest trees in cocoa plantations to vary the neighborhood would participate in the natural regulation of these diseases such as moniliosis and brown rot (Curtet, 2015) .Several ways of using trees associated with cocoa trees have been determined, including shade for cocoa trees, medical services, demarcation, fertilisation, etc. However, forest species are involved in greater numbers in the various types of use. This may be due to the greater number of trees in the orchard. In fact, 26 forest species and 5 fruit trees are used to shade the cocoa tree. Twenty-four forest species are used by growers for medicinal purposes, compared with 9 fruit species. Thirteen (13) forest species, compared with 6 fruit species, are used to demarcate plots and 10, compared with 2 fruit species, are used to fertilise the soil. Of course, 19 forest species are used as timber, while no fruit species are used as timber. Finally, several other species are used for food purposes, some to mark out fields, others as fertilisers and for spiritual reasons. From a nutritional point of view, 14 fruit species are involved, compared with 9 forest species.

CONCLUSION

A study of agroforestry systems in the Ivory Coast revealed the existence of traditional agroforestry systems, although these are often not very dense or structured. These systems, largely made up of residual or spontaneous forest species and a small proportion of fruit trees, reflect a form of agroforestry empirically integrated into farming practices. The majority of farmers recognise the multiple benefits of trees associated with cocoa trees, in particular shade, fertilisation, consumption, etc. However, certain disadvantages, such as water competition and the proliferation of diseases and pests, have also been noted. All the information obtained from this study will be used as a tool to assist in the development of modern, high-performance agroforestry systems, i.e. the reasoned integration into cocoa trees of useful species, both forest and fruit, to ensure the sustainability of cocoa production.

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