Impact of Agroforestry Systems on Mineral Fertility of Soils under Cocoa Trees in Toumodi, Côte D'ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. Authors NKR and KAG designed the study, performed the statistical analysis, wrote the protocol, and drafted the first version of the manuscript. Authors VBBNB and BS managed the analyses of the study. All authors read and approved the final manuscript.

Article Information

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ABSTRACT

Aims: To evaluate the impact of different agroforestry systems on the mineral fertility of soils under cocoa trees.
Place and duration of study: The experiment was conducted in the field from June to August 2020 in three types of cocoa-based agroforestry systems identified in Toumodi (Côte d'Ivoire) between the northern latitudes 6°19'37 and 6°34'51 and the western longitudes 5°19'58 and 5°20'02. in the forest-savanna transition zone
Methodology: Agroforestry systems define a method of setting up plantations associating various trees with cocoa trees. The choice of cocoa plantations was guided by the density of trees associated with cocoa trees defining a typology of agroforests (simple, mixed or complex). Thus, in

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each agroforestry system considered, three delimited plots of 100 m2 were randomly placed to make a floristic inventory of the species encountered and each time to take elementary soil samples in the first horizons at 0-20 cm and 20 - 40 cm depth to constitute the composite samples for chemical analyses in the laboratory.

Results: The study identified and recorded floristically, 17 families (*Anacardiaceae, Apocynaceae, Arecaceae, Bombacaceae, Caricaceae, Combretaceae, Euphorbiaceae, Invingiaceae, Lauraceae, Meliaceae, Mimosaceae, Moraceae, Musaceae, Myristicaceae, Rutaceae, Sterculiaceae, Verbenaceae*) distributed in 27 local plant species of which 55.55% of the species and a density of 55 trees/hectare in SAGS, 70.37% of the species and a density of 155.33 trees/hectare in MAGS and 81.40% of the species 224.33 trees/hectare in CAGS. These arboricultural species introduced or maintained in the plantations are generally species with shade, food, economic or medicinal interests. In terms of the chemical fertility generated, it appears that the contents of major elements and trace elements, as well as the clay-humus complex of the soils under cocoa trees were globally satisfactory and more important in the superficial horizons at a depth of 0-20 cm than in the underlying horizon of 20-40 cm, whatever the type of agroforestry system considered, but much more so in MAGS than in CAGS and SAGS in decreasing order. The different positive (R=0.80) or negative (R=-0.80) correlations established between the mineral elements in the surface horizons contribute to enrich the soil by synergistic or antagonistic effects in the agroforestry systems of Toumodi, Côte d'Ivoire.

Conclusion: The study showed that each forest agroforestry system has distinct characteristics that can be summarized mainly by its floristic diversity and density of associated trees. They are all not only preservers of a certain level of biodiversity and chemical fertility of the soils under cocoa trees, but much more so at 0-20cm than at 20-40cm. However, AGM would be more likely to improve production in a sustainable way by its capacity to establish a nutritional balance in the soil. It can be recommended during the establishment of cocoa plantations in Côte d'Ivoire.

1. INTRODUCTION

Low crop yields in sub-Saharan African countries are generally due to the poverty of natural soil nutrients and low input use, combined with the excessive presence of low-yielding traditional varieties that are susceptible to diseases and adverse weather conditions [1,2]. Also, soil fertility under old cocoa trees is experiencing a progressive degradation of nutrients, notably organic carbon, nitrogen, phosphorus and potassium, as exports of these mineral elements through cocoa fruits are not compensated [3,4]. These constraints explain the excessive area in Africa to improve productivity and compensate for low yields [1]. The cocoa tree (*Theobroma cacao L.*), whose cultural requirements correspond to the edaphic and climatic conditions of the intertropical zone, does not escape this reality, although this crop can be adapted to a great diversity of biophysical environments, soil types and climates [5,6]. It is cultivated in the field under different agroforestry systems, including simple, mixed and complex depending on the density and importance of trees associated with the field. Work carried out by [7] and [8] has shown that these different

cocoa-based agroforestry systems still exist in Côte d'Ivoire and in the department of Toumodi. However, very little work has been published on the impact of cocoa-based agroforestry systems and/or "traditional" agroforests on soil chemical properties. It is in this perspective that our study entitled "Impact of agroforestry systems on the mineral fertility of soils under cocoa trees in Toumodi, Côte d'Ivoire" is being conducted. This study aims to evaluate the impact of different agroforestry systems on the mineral fertility of soils under cocoa trees in order to sustain these systems and support cocoa cultivation.

2. MATERIALS AND METHODS

2.1 Study Area Description

The work was carried out in June 2020 and completed in August 2020 in the department of Toumodi in Kokumbo (between 6°19'37.81'' N and 6°34'51.18'' N and between 5°19'58.35'' W and 5°20'02.54'' W) located in the center of Côte d'Ivoire, in the forest-savanna transition zone (Fig.1). The climate is transitional equatorial with bimodal rainfall ranging from 800 to 1090 mm/year. It is characterized by an average

temperature of 27°C and an average relative humidity of 70%. The vegetation is a mosaic of Guinean savannahs dominated by Poaceae (*Olyra latifolia; Leptaspis zeylanica*) and dense semi-deciduous rainforests that contain tree species such as Sterculiaceae (*Triplochiton scleroxylon; Mansoniaaltissima*) Moraceae (*Antiaris toxicaria var. africana; Milicia regia*), Ulmaceae (*Celtis spp.*) and Apocynaceae (*Funtumia elastica*). The soils of the region are underlain by extensive granitic, metamorphic and schistose rock massifs. They are represented as a complex of medium to highly desaturated ferrallitic soils and reworked tropical ferruginous soils [9].

2.2 Plant Material

The plant material is made up of three types of agroforests or simple agroforestry systems (SAGS), mixed agroforestry systems (MAGS) and complex agroforestry systems (CAGS) based on cocoa trees identified in the study area on the one hand, and on the other hand, composite soil samples taken under these agroforestry systems. Simple agroforestry

systems are characterized by a low density of associated trees with an open canopy and a high proportion of exotic plant species (Fig. 2A). Complex agroforestry systems have a closed canopy and a high density of local plant species (Fig. 2B), and mixed agroforestry systems are intermediate between the two and are characterized by a moderately open canopy and a moderate density of local species (Fig. 2C).

2.3 Methods

2.3.1 Collection of floristic parameters of the vegetation

In the field, the choice of cocoa plantations was guided by the typology of agroforests (simple, mixed and complex). In each agroforestry system, three delimited plots of 100 m² (10 m x 10 m) were randomly placed to identify the species encountered and to evaluate their floristic diversity. Species not identified in the field were collected and a herbarium was created to allow their identification in the laboratory from the flora proposed by [10] and [11].
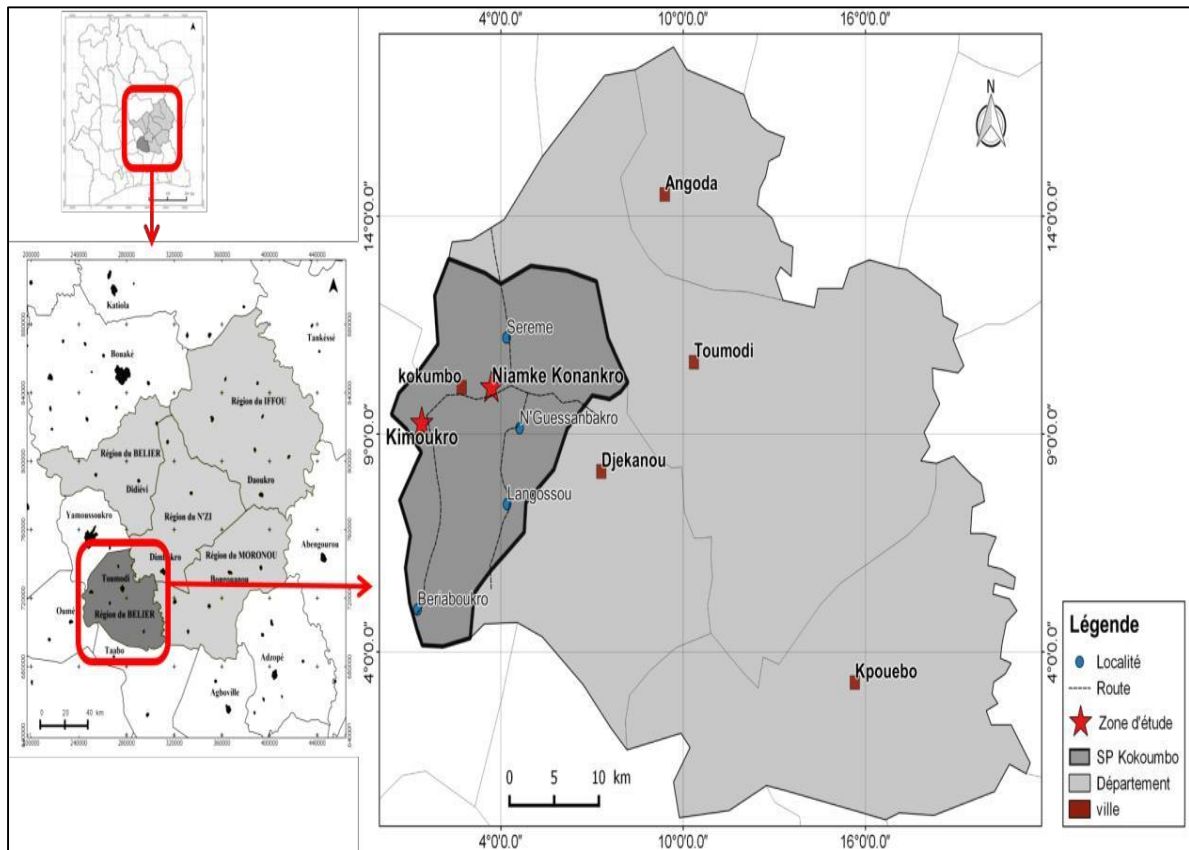

Fig. 1. Location of the sub-prefecture of Kokumbo in the department of Toumodi in central Côte d'Ivoire
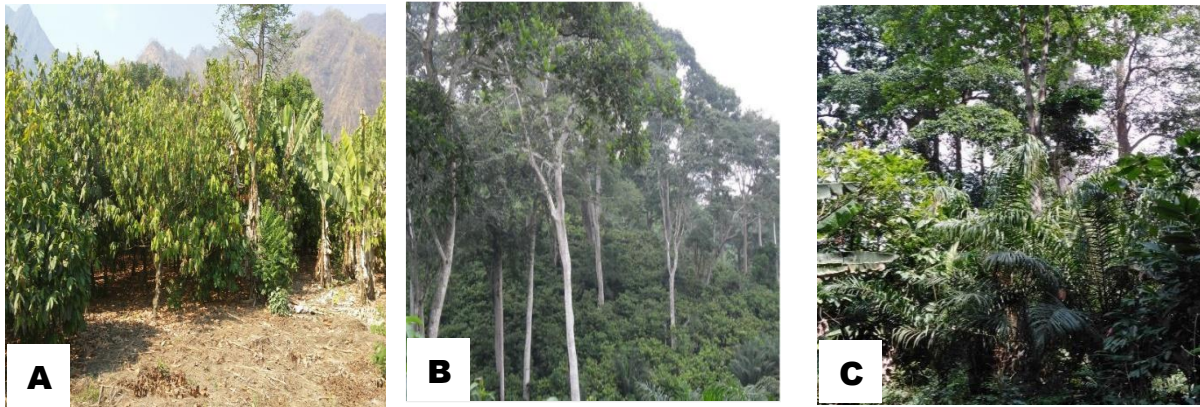
Fig. 2. Different types of agroforestry systems in the study area (A: simple agroforestry system; B: complex agroforestry system; C: mixed agroforestry system)

2.3.2 Sampling and analysis of agroforestry system soils

In each plot, the elementary soil samples were taken with an auger in the 0-20 cm and 20-40 cm horizons in a zigzag pattern along the longest diagonal. For the same plantation, two composite samples of incremental samples were taken according to the sampling depth for laboratory analysis. Chemical analyses of the composite sample were carried out in the soil and plant laboratory of the Institut National Polytechnique Félix Houphouët-Boigny (INP-HB) in Yamoussoukro, Côte d'Ivoire, and included pH measurement (electronic glass pH meter in a soil/solution ratio of 1/2.5), determination of total carbon (Walkley & Black method) and organic matter (C x 0, 72), total nitrogen (Kjeldahl method), assimilable phosphorus (Olsen-Dabin method), exchangeable bases and cation exchange capacity-CEC (Ammonium acetate solution rinse extraction), calcium-Ca and magnesium-Mg (Atomic absorption), potassium-K (Flame spectrophotometer), using standard laboratory methods of analysis.

2.4 Data Statistical Treatment

Data analysis was done using descriptive statistics methods and analysis of variance (ANOVA) performed with SAS software version 9.4. Means were separated using the Newman and Keuls test at the 5% probability level. Pearson correlation analyses (r) were also performed to establish relationships between chemical parameters. Correlations are shown, positive (+ R) or negative (- R) change at the correlation coefficient R=0.80 and relationships are significant at the α=0.05 threshold.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Floristic characteristics of agroforestry systems in cocoa plantations

The inventory of plant species associated in the agroforestry system considered identified as cocoa plantations is presented in Table 1. A total of 27 local plant species, scientifically recognized, grouped in 17 main families were identified during the study. The species of the family Anacardiaceae, Apocynaceae, Arecaceae, Bombacaceae, Caricaceae, Combretaceae, Euphorbiaceae, Invingiaceae, Lauraceae, Meliaceae, Mimosaceae, Moraceae, Musaceae, Myristicaceae, Rutaceae, Sterculiaceae, Verbenaceae were counted. Also, of the 27 plant species recorded, 15 were identified in simple agroforestry system (SAGS) or 55.55% of species, 19 were present in medium agroforestry system (MAGS) or 70.37% of species and 22 species in complex agroforestry system (CAGS) or 81.40% of plant species. In the overall distribution, we note that some plant species recorded are present in all three agroforestry systems while other plant species are present in only two or one of the agroforests. More explicitly, it was noted that species belonging to the family Anacardiaceae, Arecaceae, Bombacaceae Euphorbiaceae and Sterculiaceae were present in the three agroforestry systems considered, that is, in the simple agroforestry system (SAGS), the medium agroforestry system (MAGS) and the complex agroforestry system (CAGS) with 32.14% of the plant species recorded. Combretaceae, Meliaceae, Mimosaceae, Moraceae, and Verbenaceae were

more representative in the medium agroforestry system (MAGS) and the complex agroforestry system (CAGS) with more than 28, 57% of the plant species identified in the same proportions (25%) as Caricaceae Lauraceae, Musaceae, Rutaceae, and Sterculiaceae identified in the simple agroforestry system (SAGS) and the complex agroforestry system (CAGS). The Anacardiaceae and Apocynaceae with 7.14% of species were in the medium agroforestry system (MAGS) and the simple agroforestry system (SAGS). Similarly, Invingiaceae and Moraceae as well as Myristicaceae and Sterculiaceae were observed only representatives in each of the agroforestry systems with 7, 14 % of plant species.

3.1.2 Density of plant species associated with cocoa trees in agroforestry systems

The density per hectare of all trees associated with cocoa trees in each agroforestry system was determined (Table 2). The average values

obtained indicate that there is a significant effect (p = 0.05) of the agroforestry systems on the density of cocoa trees as well as that of the associated species. Indeed, the density of cocoa trees in SAGS (1456, 67 trees/hectare) was higher than that of MAGS and CAGS, which had statistically identical values of 1120 to 1206 trees/hectare. Similarly, the agroforestry systems significantly influenced the density of plant species. This was reflected in the low density of plant species in AGS (55 trees/hectare) compared to 155 trees/hectare for MAGS and 224 trees/hectare for CAGS. More explicitly, the higher the density of cocoa trees in the plantation as indicated by the simple agroforestry system (SAGS), the less trees are associated with it and vice versa.

3.1.3 Chemical characteristics

The results of the different chemical analyses of soils under cocoa trees in the different agroforestry systems are recorded in Table 3.

Table 1. Plant species associated with cocoa farming in the study area

	Species	Species scientific	Species	Species			
	Acajou	Khaya grandifoliola	Meliacea	mP	-	+	+
	Adrin	Pycnathus	Myristica	mP	-	+	-
	Akpi	Ricinodendron	Euphorbi	mP	+	+	+
	Alla	Milicia sp	Moracea	MP	-	+	+
	Amien	Alstonia boonei	Apocyna	MP	+	+	-
	Avocatier	Persea americana	Lauracea	Mp	+	-	+
	Bananier	Musa spp	Musacea	G	+	-	+
	Citronnier	Citrus limon	Rutaceae	Mp	+	-	+
	Colatier	Cola nitida	Sterculia	mP	+	+	+
	Fraké	Terminalia	Combret	MP	-	+	+
	Framiré	Terminalia	Combret	MP	-	+	+
	Gôli kpakpa	Albizia zygia	Mimosac	mP	-	+	+
	Kaklou	Irvingia	Invingiac	MP	-	-	+
	Kanankpliya	Vitex sp	Verbenac	Mp	-	+	+
	Kpouka	Bombax	Bombaca	MP	+	+	+
	Logblô	Ficus mucuso	Moracea	mP	-	+	+
	Louklou	Entandrophragma	Meliacea	MP	-	+	+
	Manguier	Mangifera indica	Anacardi	mP	+	+	-
	N'gnien	Ceiba pentandra	Bombaca	MP	+	+	+
	Offi djedje	Antiaris africana	Moracea	mP	-	+	-
	Oranger	Citrus sinensis	Rutaceae	Mp	+	-	+
	Palmier à	Elaeis guineensis	Arecacea	mP	+	+	+
	Pamplemou	Citrus grandis	Rutaceae	Mp	+	-	+
	Papayer	Carica papaya	Caricace	Mp	+	-	+
	Samba	Triplochiton	Sterculia	MP	-	+	-
	Trouman	Spondias mombin	Anacardi	Mp	+	+	+
	Walê	Cola gigantea	Sterculia	mP	+	-	+
Total Species	27	27	17	-	15	19	22

G = geophyte; mp = microphanerophyte from 2 to 8 m height; Mp = mesophanerophyte from 8 to 32 m height;
MP= megaphanerophyte more than 32 m height, (+) = presence of the species, (-) = absence of the species
SAGS = smple agroforestry system, MAGS= medium agroforestry system, CAGS= complexe agroforestry system

Table 2. Density of cocoa trees and associated plant species according to agroforestry systems in the study area

	Density of plant species in agroforestry systems per l'hectare	
Agroforestry systems	**Density of cocoa trees**	**Density of plant species associated with cocoa trees**
SAGS	1456. 67a	55. 00c
MAGS	1206. 67b	155. 33b
CAGS	1120. 00b	224. 33a
Mean	1261. 11	144. 88
Var.Coéf. (%)	7. 92	19. 99
p Value	< 0. 019	< . 001

Values in the same column followed by the same letter are not statistically different at the α =0.05 threshold
SAGS = smple agroforestry system, MAGS= medium agroforestry system, CAGS= complexe agroforestry system

3.1.3.1 Soil pH

The comparison of the average pH values indicates that there was no statistically significant difference between the pH of the soils at 0-20 cm and 20-40 cm in SAGS, MAGS and CAGS. Moreover, these pH values vary between 6.70 and 7.00, characterizing a low acid soil whatever the agroforestry system.

3.1.3.2 Organic matter and major elements of the studied soil

It was observed that no significant differences were recorded at 0-20 cm and 20-40 cm horizons for organic matter and carbon, total nitrogen and assimilable phosphorus content in SAGS and CAGS. On the other hand, there was significant variability in the averages of organic matter and carbon, nitrogen and assimilable phosphorus in MAGS in the thicknesses of the horizons concerned. More explicitly, the different mineral element contents (OM, C, N, Pass) were on average higher at 0-20 cm surface layer than at 20-40 cm layer in all agroforestry systems considered, except for MAGS-assimilable phosphorus, which showed higher content values in the 20-40 cm layer than at 0-20 cm layer. Also, it should be noted that the highest contents of mineral elements in OM, C, N and Pass were noted in MAGS than in SAGS and CAGS, as well as in 0-20 cm as in 20-40 cm, thus testifying a good mineralization and humification of the organic matter in the horizons of this agroforestry system

3.1.3.3 Exchangeable cations and cation exchange capacity of the studied soils

It is noted that no significant difference in the average values of exchangeable cations was observed between the different agroforestry

systems on the one hand and on the other hand on the 0-20 cm and 20-40 cm layers whatever the agroforestry system, except for magnesium and CEC which showed significant average values in SAGS on the one hand and in MAGS on the other hand for magnesium and the sum of cations. On the other hand, it was noted that, overall, the average values of exchangeable cations and cation exchange capacity were also higher in MAGS than in the other agroforestry systems, although statistically no significant difference was observed.

3.1.4 Correlation between chemical parameters of the studied agroforstry systems soils

The values of correlations established between the chemical parameters of the soils of the studied agroforestry systems at the depth 0-20 cm were presented in Tables 4B and 4C.

Overall, positive and negative correlation values are observed between the chemical parameters of the soils, whatever the agrosystem considered at the 0-20 cm depth.

In SAGS (0-20cm), Table 4A explicitly presents positive and non-significant correlation values (R = 0.80; *p* >0.05) between pH with organic matter (OM), carbon (C), nitrogen (N), C/N ratio, potassium (K) and sodium (Na) on the one hand, and on the other hand between nitrogen (N) and C/N ratio, CEC, magnesium (Mg) and potassium (K). Similarly, a similar correlation was maintained between C/N ratio, potassium (K) and calcium, between calcium and sodium, between potassium and sodium and finally between organic matter, nitrogen, C/N ratio, magnesium and potassium except for carbon where the correlation was positive and significant (R = 0.80; *p* = 0.05) A positive and significant correlation (R

= 0.80; *p* = 0.05) was also observed between CEC and magnesium. On the other hand, assimilable phosphorus had negative and non-significant correlation values (R = -0.80; *p* >0.05) with pH, organic matter, carbon, nitrogen, and sodium and negative and significant correlation values (R = -0.80; *p* = 0.05) with C/N ratio and potassium.

Table 3. Chemical analysis values of agroforestry systems soils

| Parameters | Chemical element values of cocoa-based agroforestry systems | | | | | | |
| | SAGS | | MAGS | | CAGS | | |
	Horizon (0-20 cm)	Horizon (20-40 cm)	Horizon (0-20 cm)	Horizon (20-40 cm)	Horizon (0-20 cm)	Horizon (20-40 cm)	*norms*
pH	6.70a	6.70a	6.85a	6.75a	7.00a	6.80a	*6-7*
OM (%.)	15.86a	9.69a	**19.90a**	**17.88b**	19.23a	11.86a	*3.6-6.5*
C (%)	9.22a	5.63a	**11.52a**	**10.37b**	11.18a	6.89a	*6.2-11.2*
Ntotal (p.c.)	0.71a	0.43 a	**0.87a**	**0.75b**	0.83a	0.51a	*0.1-0.15*
C/N	1.91a	11.99a	**13.23b**	**13.86a**	13.46a	13.24a	*11-15*
Pass (ppm)	103.45a	129.95a	**107.25a**	**99.15b**	101.43a	150.93a	*50-100*
Ca (cmol.kg^{-1})	4.93a	5.51a	6.31a	5.14a	6.41a	4.79a	*5-8*
Mg (cmol.kg^{-1})	**2.96a**	**2.07b**	**3.87a**	**2.92b**	3.37a	2.28a	*1.5-3*
K (cmol.kg^{-1})	0.09a	0.07a	0.11a	0.07a	0.11a	0.08a	*0.15-0.25*
Na (cmol.kg^{-1})	0.18a	0.11a	0.13a	0.10a	0.13a	0.11a	*0.3-0.7*
Sum (cmol.kg^{-1})	8.17a	7.75a	**10.43a**	**8.81b**	10.02a	7.27a	*7.5-15*
CEC (cmol.kg^{-1})	**28.00a**	**22.90b**	30.60a	26.50a	23.53a	25.33a	*10-20*
V (%)	29.37a	33.94a	34.17a	33.23a	38.30a	28.17a	*60-90*

Values followed by the same letter are not statistically different at the α = 0.05 threshold within a line for uppercase between agroforestry systems and for lowercase between layers of an agroforestry system respectively SAGS = smple agroforestry system, MAGS= medium agroforestry system, CAGS= complexe agroforestry system
Normative reference values [12,13,14,15]

Table 4. Matrix of correlation between chemical parameters of the studied agroforestry system soils at the depth of 0-20 cm

(A)						SAGS (0 – 20 cm)					
	pH	OM	C	N	C/N	Pass	CEC	Ca^{2+}	Mg^{2+}	K$^+$	Na$^+$
pH	1										
OM	**0.88**	1									
C	**0.88**	**1.00***	1								
N	**0.82**	**0.99**	0.99	1							
C/N	**0.95**	**0.98**	0.98	0.96	1						
Pass	**-0.96**	**-0.98**	-0.98	-0.95	-099*	1					
CEC	0.39	0.78	0.78	**0.85**	0.65	-0.65	1				
Ca^{2+}	0.71	0.30	0.30	0.18	0.47	-0.47	-0.37	1			
Mg^{2+}	0.47	**0.82**	0.82	**0.89**	0.72	-0.71	**0.99***	-0.29	1		
K$^+$	**0.95**	**0.98**	0.98	0.96	0.99*	-0.99*	0.66	0.46	0.72	1	
Na$^+$	**0.96**	0.73	0.73	0.64	**0.84**	**-0.84**	0.13	**0.87**	0.22	**0.83**	1

(B)						MAGS (0 – 20 cm)					
	pH	OM	C	N	C/N	Pass	CEC	Ca^{2+}	Mg^{2+}	K$^+$	Na$^+$
pH	1										
OM	0.67	1									
C	0.67	**1.00***	1								
N	0.25	**0.89**	0.89	1							
C/N	0.25	-0.55	-0.55	**-0.87**	1						

	pH	OM	C	N	C/N	Pass	CEC	Ca^{2+}	Mg^{2+}	K$^+$	Na$^+$
Pass	0.65	**0.99***	**0.99***	**0.90**	-0.57	1					
CEC	**0.84**	**0.96**	**0.96**	.73	-0.31	**0.95**	1				
Ca^{2+}	0.79	**0.98**	**0.98**	0.79	-0.39	**0.99**	**0.99***	1			
Mg^{2+}	0.60	**0.99**	**0.99**	**0.93**	-0.63	**0.99***	**0.93**	**0.96**	1		
K$^+$	-0.40	0.41	0.41	0.78	**-0.99**	0.43	0.15	0.24	0.50	1	
Na$^+$	-0.41	0.40	0.40	0.79	**-0.98**	0.42	0.14	0.23	0.49	**0.99***	1

(C)	CAGS (0 – 20 cm)										
	pH	**OM**	**C**	**N**	**C/N**	**Pass**	**CEC**	**Ca^{2+}**	**Mg^{2+}**	**K$^+$**	**Na$^+$**
pH	1										
OM	**-0.99**	1									
C	**-095**	**1.00*****	1								
N	**-0.98**	**0.99***	**0.99***	1							
C/N	**-0.93**	**0.89**	**0.89**	0.86	1						
Pass	**-0.93**	**0.96**	**0.96**	**0.97**	0.72	1					
CEC	**-0.97**	**0.95**	**0.95**	**0.93**	**0.99**	**0.82**	1				
Ca^{2+}	**0.99***	**-0.99***	**-0.99***	**-0.99**	**-0.91**	**-0.94**	**-0.96**	1			
Mg^{2+}	-0.35	0.26	0.26	.022	0.67	-0.02	0.55	-0.31	1		
K$^+$	**0.84**	-0.79	-0.79	-0.76	**-0.98**	-0.57	-0.94	0.82	**-0.80**	1	
Na$^+$	-0.42	0.51	0.51	0.55	0.06	0.74	0.21	-0.46	-0.69	0.12	1

Values with a * sign mean: * = positive or negative significant correlation (P=0, 05); * * = highly significant positive or negative correlation (P<0.005); *** = highly significant positive or negative correlation (P<0.0005
SAGS = smple agroforestry system, MAGS= medium agroforestry system, CAGS= complex agroforestry system

For MAGS (0-20cm), Table 4B indicates that, organic matter (OM) showed positive and significant correlation values (R = 0.80; p = 0.05) with carbon and also positive and non-significant correlations (R = 0.80; p >0.05) with nitrogen, CEC, calcium and magnesium. A similar result of positive and non-significant correlation (R = 0.80; p >0.05) was also obtained between nitrogen, assimilable phosphorus and carbon, between carbon and CEC, between calcium and magnesium, between CEC, pH and magnesium and between calcium and magnesium. Also, assimilable phosphorus was positively and significantly correlated (R = 0.80; p =0.05) with organic matter, carbon and magnesium and then in the same direction of correlation as between CEC and calcium, between potassium and sodium. On the other hand, negative and non-significant correlations (R = -0.80; p >0.05) were obtained between C/N, nitrogen, potassium and magnesium.

Table 4C shows the correlation values between the mineral elements in CAGS (0-20cm). We note that positive and non-significant correlations (R = 0.80; p>0.05) were established between organic matter, C/N ratio, assimilable phosphorus and CEC, between C/N ratio, organic matter, carbon, nitrogen and CEC, between pH and potassium and positive and significant correlation values (R = 0.80; p=0.05) between carbon, organic matter, nitrogen,

between pH and calcium. On the other hand, negative and significant (R = -0.80; p=0.05) or non-significant (R = -0.80; p>0.05) were noted between pH and organic matter, carbon, nitrogen, C/N ratio, assimilable phosphorus and CEC on the one hand and on the other hand between calcium and organic matter, carbon, nitrogen, C/N ratio, assimilable phosphorus and CEC, finally between potassium and C/N ratio, magnesium.

At the depth of 20-40 cm (Table 5A, 5B and 5C), a similar result of variable positive or negative and significant or non-significant correlations was also obtained between soil mineral elements in SAGS (Table 5B), MAGS (Table 5B) and CAGS (Table 5C).

In contrast, in SAGS (20-40cm), positive and non-significant correlation values ((R = 0.80; p>0.05) were observed between pH and organic matter, carbon (C), nitrogen (N), C/N ratio, calcium (Ca) and potassium. The C/N ratio had a similar correlation with organic matter, carbon, nitrogen, calcium and also potassium. Other positive and non-significant correlations between CEC and magnesium and sodium were also noted. On the other hand, a positive and significant correlation ((R = 0.80; p=0.05) between organic matter, carbon, nitrogen, calcium, potassium on the one hand and between nitrogen, calcium and potassium on the other hand, as well as the correlation between

calcium and potassium, between magnesium and sodium. No negative correlation was noted between the mineral elements.

For MAGS (20-40cm) Table 5B indicates that pH had positive and non-significant correlated values (R = 0.80; p>0.05) with CEC and magnesium. Likewise, the correlations obtained between assimilable phosphorus, organic matter, carbon, nitrogen and C/N ratio, between potassium, organic matter, carbon, nitrogen and assimilable phosphorus, as well as the one observed between sodium, organic matter, carbon, nitrogen and assimilable phosphorus were positive and not significant. On the other hand, the correlation between organic matter, carbon, nitrogen on the one hand, and between carbon and nitrogen, calcium and magnesium on the other hand, as well as the one established between CEC, calcium and magnesium had positive and significant correlated values. (R = 0.80; *p*=0.05). The only negative and insignificant correlations (R = -0.80; *p*>0.05) were between the C/N ratio with organic matter, carbon, nitrogen, potassium and sodium.

In CAGS (20-40cm), organic matter, carbon, nitrogen, C/N ratio, assimilable phosphorus, CEC, calcium and sodium were correlated positively or negatively, sometimes significantly or non-significantly with each other. It should be noted that all the values of negative, significant or non-significant correlations observed in the different correlation matrices have an antagonistic effect between the chemical parameters related to each other whatever the agrosystem and the depth considered.

3.2 Discussion

3.2.1 Plant species associated with cocoa production and agroforestry system

From this study it appears that the tree species identified are not specific to each agroforestry system, although there is a difference in density according to the type of agroforestry system. This makes it possible to define the different types of agroforestry systems as simple with 55.55 % of associated species, mixed with 70.37 % of associated species and complex with 81.48 % of associated species. The composition and/or density of floristic species associated with cocoa farming is based on the farmer's experience in cultivation practices, the variety grown or the economic value of the associated species [16].

Table 5. Matrix of correlation between chemical parameters of the soils of the agroforestry systems studied at a depth of 20-40 cm

(A)		SAGS (20-40cm)									
	pH	OM	C	N	C/N	Pass	CEC	Ca²⁺	Mg²⁺	K⁺	Na⁺
pH	1										
OM	**0.94**	1									
C	**0.94**	**1.00*****	1								
N	**0.94**	**1.00****	**1.00****	1							
C/N	**0.98**	**0.99**	**0.99**	**0.99**	1						
Pass	0.42	0.09	0.09	0.08	0.24	1					
CEC	0.12	0.45	0.45	0.46	0.31	-0.85	1				
Ca²⁺	**0.93**	**1.00*****	**1.00*****	**1.00****	**0.98**	0.07	0.47	1			
Mg²⁺	0.44	0.71	0.71	0.72	0.60	-0.63	**0.94**	0.73	1		
K⁺	**0.94**	**1.00*****	**1.00*****	**1.00****	**0.98**	0.07	0.47	**1.00****	0.73	1	
Na⁺	0.43	0.71	0.71	0.72	0.60	-0.63	**0.94**	0.73	**1.00****	0.73	1

(B)		MAGS (20-40cm)									
	pH	OM	C	N	C/N	Pass	CEC	Ca²⁺	Mg²⁺	K⁺	Na⁺
pH	1										
OM	0.31	1									
C	0.31	**1.00*****	1								
N	0.35	**1.00*****	**1.00*****	1							
C/N	-0.58	**-0.95**	**-0.95**	**-0.97**	1						
Pass	0.45	**0.99**	**0.99**	**0.99**	**0.99**	1					
CEC	**0.99**	0.45	0.45	0.49	-0.69	0.57	1				
Ca²⁺	**1.00*****	0.37	0.37	0.41	-0.63	0.50	**1.00*****	1			
Mg²⁺	**1.00**	0.43	0.43	0.48	-0.68	0.56	**1.00****	**1.00*****	1		
K⁺	0.16	**0.99**	**0.99**	**0.98**	**-0.90**	**0.95**	0.31	0.22	0.30	1	
Na⁺	0.53	**0.97**	**0.97**	**0.98**	**-1.00**	**1.00**	0.65	0.58	0.64	**0.92**	1

(C)	CAGS (20-40cm)										
	pH	OM	C	N	C/N	Pass	CEC	Ca^{2+}	Mg^{2+}	K$^+$	Na$^+$
pH	1										
MO	-	1									
C	-	1.00***	1								
N	-	1.00*	1.00*	1							
C/N	-	1.00*	1.00*	1.00*	1						
Pass	-	-0.90	-0.90	-0.91	-0.87	1					
CEC	-	0.98	0.98	0.98	0.97	0.97	1				
Ca^{2+}	-	1.00*	1.00*	1.00*	0.99	-0.93	0.99	1			
Mg^{2+}	-	0.99	0.99	0.99	0.98	-0.95	1.00*	1.00*	1		
K$^+$	-	-0.52	-0.52	-0.52	-0.47	0.84	-0.68	-0.59	-0.64	1	
Na$^+$	-	-0.99*	-0.99*	-0.99*	-0.99	0.93	-0.99	-1.00**	-1.00*	0.59	1

*Values with a * sign mean: * = positive or negative significant correlation (P=0, 05); * * = highly significant positive or negative correlation (P<0.005); *** = highly significant positive or negative correlation (P<0.0005*
SAGS = smple agroforestry system, MAGS= medium agroforestry system, CAGS= complex agroforestry system

These characteristics of the agroforestry systems are directly linked to the technical itineraries of the cultivation practices chosen by the farmers by tradition or by experience [16]. It is noted that in the plantations, the preference of the planters is for exotic species such as *Persea americana Mill.* (Lauraceae), *Citrus spp* (Rutaceae). Generally, Kokumbo farmers with plots that are more than forty years old have opted for a high density of associated trees and therefore a complex or mixed agroforestry system because the climatic conditions are considered unfavorable for cocoa cultivation [17]. This practice has also been observed in the dense forest zones and transition zones of Côte d'Ivoire [16,18]. Similarly, in Cameroon, [19] and [20] have also described similar cultivation practices. For these authors, this is a selection process common to tropical agroforestry systems, aimed at diversifying the income from plantations. As for [21] and [22], they explain the cultivation practices based on the simple agroforestry system as a new technique aimed at reducing nutritional competition with cocoa trees. In addition, the introduction and/or maintenance of local species belonging to the families Sterculiaceae, Anacardiaceae, Euphorbiaceae, Apocynaceae, Moraceae, Combretaceae, Lauraceae, Musaceae, Rutaceae, Caricaceae in the conduct of plantations are observed. Indeed, farmers consider these trees to be species that are not only compatible with cocoa production but also species that have the role of combating excessive weediness and, in addition, serve for self-consumption and income diversification. In sum, the preference of species results from a compromise between their domestic uses and their impact on soil fertility under cocoa [23;24]. In addition to this, the choice of local plant species by farmers is guided secondarily by their contribution to the medical and ornamental plan [25,26,27].

3.2.2 Chemical fertility of the soil in cocoa-based agroforestry systems

This study also showed that the overall fertility of Kokumbo soils is satisfactory if we take into account the values obtained compared to the normative values referred by [12,13,14,15]. Also, it was found that the contents of major elements and trace elements, as well as the clay-humus complex, which characterize the mineral fertility of soils under cocoa trees and which make possible the mineral nutrition of the plant were more important in the superficial horizons at the depth of 0-20 cm whatever the type of agroforestry system, but much more in mixed and complex agroforestry systems In fact, the introduction and/or maintenance of local species in the plantations at the desired density establishes, through a shading effect and by avoiding possible soil degradation, a mineral enrichment and balance between the different agroforestry systems. The persistence of vegetation covering the soil, which, through the fall of leaves and plant debris, constitutes a sustainable source of litter to the soil, contributing to the improvement of the physico-chemical properties of the soil [28,29]. The decomposition of litter or organic horizon, through processes of mineralization and humification, in fact, contribute to enrich the soil in major mineral elements in trace minerals and humus. Also [30].affirm that the fall of the leaves of cocoa trees and associated species, ensures part of the fertility of the soil of agroforestry systems and thus limits the use of fertilizers on these plots. Furthermore, the positive correlations established between chemical

parameters contribute to enriching the soil of agroforestry systems through a synergistic effect, whereas negative correlations ensure a balance of nutrients in the soil through an antagonistic effect. This is what justifies the satisfactory fertility of soils in cocoa-based agroforestry systems. Studies carried out in Côte d'Ivoire and elsewhere [15] and [31] recommended mineral fertilization by chemical fertilizers. Although mineral fertilization is a satisfactory solution for the time being, it is not sustainable and is only effective if the recommended amendment is repeated. On the other hand, one could opt for an agroforestry system based on cocoa trees where the associated plants are chosen according to their capacity to establish a nutritional balance in the soil. The physico-chemical results obtained reinforce the knowledge on the importance of agroforestry in planting.

4. CONCLUSION

This study has shown that each forest agroforestry system has distinct characteristics that are mainly summarized in the floristic diversity and density of associated trees. The agroforestry systems studied not only conserve a certain level of biodiversity but also conserve and maintain the chemical parameters of the soils under cocoa trees that can sustainably improve cocoa production. Although some studies carried out in Côte d'Ivoire and elsewhere recommended mineral fertilization with chemical fertilizers, it would be appropriate to opt for an mixed agroforestry system based on cocoa trees where the associated plants are chosen according to their capacity to establish a nutritional balance in the soil. The physico-chemical results obtained reinforce the knowledge on the importance of agroforestry in planting.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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