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Study of Potential Edaphic Chemical Factors in the Prevalence of Swollen Shoot Disease of Cocoa in the Marahoué Region (Côte d'Ivoire)

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Abstract

This study looks at the prevalence of swollen shoot disease in cocoa plantations in the Marahoué region of Côte d'Ivoire, a key cocoa-producing area. Cocoa accounts for around a third of the country's export earnings, but production is under threat from the swollen shoot virus, which is causing major yield reductions. The aim of the study is to establish a link between the chemical properties of the soil and the presence of the disease, in particular the levels of carbon, nitrogen, phosphorus, calcium and acidity (pH) in the soil. Specifically, soils from healthy plots were compared with soils from infested plots in six plantations in the Bouaflé and Kononfla sub-prefectures. The results show that soils from infested plots have lower phosphorus levels and near-neutral acidity in the 20 - 40 cm soil layer, while soils from healthy plots are slightly acidic and contain more calcium and phosphorus. These chemical differences seem to influence the prevalence of the virus. Low phosphorus levels appear to be a key factor in the vulnerability of cocoa trees to the disease. The study therefore suggests that any strategy to combat swollen shoot should include better soil management, incorporating factors such as soil depth and the availability of essential nutrients. In addition, an assessment of the micro-organisms present in the soil could provide further information on the interactions between the soil and the disease.

Keywords

Soil, Chemical Properties, Cocoa, Swollen Shoot, Marahoué Region

1. Introduction

With a production of 1.7 million tonnes, *i.e.* 42 pc of the world supply, Côte d'Ivoire is the world's leading producer of cocoa beans [1]. Overall, the cocoa industry contributes around a third of the country's export earnings and 20 pc of national wealth [2]. On a social level, around six hundred thousand farm managers provide a livelihood for nearly six million people [3], constituting the main source of income for thousands of small farmers in rural areas. The areas of greatest production were initially the east and centre-east of the country. With climate change and soil impoverishment, the cocoa loop is now located in the Centre-West, where production exceeds 36% of national output. The Marahoué region, which is one of the major production areas today, is under serious threat from the cocoa swollen shoot disease, the main biotic constraint on cocoa production, capable of causing significant reductions in yields. This is a viral disease transmitted by mealybugs of the Pseudococcidae family, the most virulent isolate of which, called Agou 1, causes intense red discolouration of young leaves, discolouration of adult leaves, swelling of stems and branches and stunting of pods.

Various methods have been put in place to combat the virus. These methods, in particular the method of uprooting diseased plants, chemical and biological control of vectors, premunition, the use of sanitary cordons and barrier crops and the selection of resistant cocoa varieties, have only made it possible to attenuate the action of the virus without being able to eradicate it completely [4]-[8]. The observation is that the search for a solution to the threat has not yet sufficiently overlooked the soil, which is the natural support for the cocoa orchard. To remedy this shortcoming, [9] conducted a study in the Marahoué region, which revealed poor morphological soil conditions, mainly a large volume of ferromanganic concretions occupying the soil, poor internal soil drainage and shallow soil compaction. This research comes at the right time to increase our knowledge of the involvement of edaphic factors in the prevalence of swollen shoot disease in cocoa farms. The overall aim is to establish a soil diagnosis of swollen shoot disease in cocoa-based on the chemical properties of the soil.

2. Materials and Methods

2.1. Study Area

The study was conducted in the administrative region of Marahoué in Côte d'Ivoire (West Africa), specifically in the sub-prefecture of Bouaflé located in the centre-east of the region and the sub-prefecture of Kononfla in the south-east. The Marahoué region itself is located in central-western Côte d'Ivoire, between latitudes 6˚58'59.999" and 6˚37'12" north and longitudes 5˚45'0" and 5˚55'12" west.

The region receives between 1800 and 2000 mm of rainfall annually, with an average temperature of 25˚C to 30˚C and a humidity level of around 75 pc. These climatic conditions are conducive to agriculture and livestock farming [10]. The Bandama Rouge or Marahoué and Bandama Blanc rivers flow through the region [11]. It lies in a transition zone between the dense forest to the south and south-west and the wooded savannah to the north and north-east [12].

The relief is made up of low plateaux, plains and hills reaching an average altitude of 260 m, giving the region a relatively flat topography. Geologically, the area belongs to the Birrimian granite and schist complex [13]. The soils are predominantly Eutric Ferralsols, with some differences between the forest and savannah zones. Acrisols are also present in the north and north-east, as well as Gleysols near watercourses [10].

2.2. Soil Sampling

A total of six cocoa plantations, evenly distributed between the sub-prefectures of Bouaflé and Kononfla, were used to collect soil data. The Bouaflé sites are located in the villages of Guessanfla (N6˚55'73.3" W5˚45'76.8"), Krayaokro (N6˚54'91.1" W5˚45'71.2") and Simporéfla (N6˚53'51.0" W5˚45'74.0"), while those of Kononfla were located in the villages of Diénembroufla (N6˚38'54.6" W5˚38'01.3"), Koumoudji (N6˚38'22.9" W5˚38'24.5") and Kayéta (N6˚38'50.2" W5˚40'06.1").

In each plantation, two useful plots were delimited: the first, measuring 100 × 100 m, was located in a healthy part of the cocoa plantation and the second, of the same size, was located in an infested part (**Figure 1**). The two plots were sufficiently far apart (at least 50 m) to avoid confusing the soils.

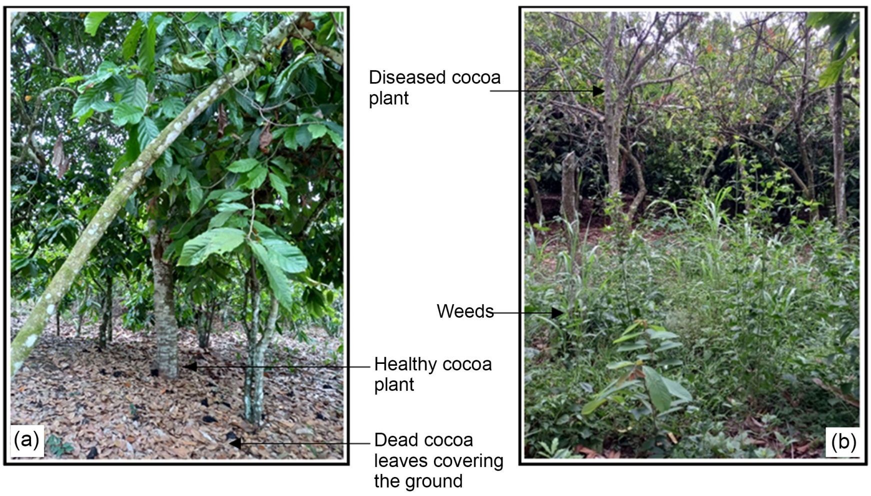

Figure 1. Views of healthy (a) and infested (b) cocoa plots explored.

In each plot, three soil sampling points were identified: P1, P2 and P3. These points correspond, in this order, to points on the plot where the cocoa trees have high, medium and low vigour. Indeed, under the conditions of the study, the level of crop development (growth, health, infestation, yield) would better reflect the state of the underlying soil [14].

At a given point, two successive samples were taken by placing the auger perpendicular to the soil and then rotating it until it reached a depth of 20 cm. The auger is then removed from the ground, along with the first soil sample. After the auger has been removed and the soil removed, the second soil sample is taken, cleaned thoroughly with water and then pushed back down to a depth of 20 cm in the hole dug in the ground for the first sample. It was the 0 - 40 cm layer that was explored, because most of the lateral roots that provide the cocoa tree with mineral and water nutrition are concentrated in this upper part of the soil, although the plant prefers well-drained soils that are at least 1.5 m deep. In total, six soil samples were taken from each useful plot, *i.e.* 12 samples from each plantation, giving a total of 72 soil samples taken throughout the study area. The samples were stored in plastic bags, labelled and taken to the laboratory for chemical analysis.

2.3. Chemical Analysis of Soils

The soil chemical properties measured are listed in **Table 1** along with the methods used. These analyses were carried out at the plant and soil analysis laboratory of the Institut Polytechnique Félix Houphouët-Boigny (Yamoussoukro, Côte d'Ivoire).

Table 1. Chemical properties of the soil determined.

Variables	Methods
pH	pH glass electrode meter [15]
Organic carbon (C)	Walkley & Black [16]
Organic matter (OM)	OM = 1724 × C
Total nitrogen (N)	Kjeldahl modified [15]
Assimilable phosphorus (P)	Olsen modified [17]
Exchangeable calcium (Ca^{2+})	Atomic absorption spectrometry [18]
Exchangeable magnésium (Mg^{2+})	
Exchangeable potassium (K^+)	
Sum of Exchangeable Bases (SEB)	SEB = $Ca^{2+} + Mg^{2+} + K^+$
Cation exchange capacity (CEC)	Kjeldahl modified [15]
Base saturation (V)	V = SEB/CEC

Based on the measurements taken, chemical balances that form part of the main indices of soil quality in cocoa farming were calculated. These indices specify that:

- exchangeable bases must be balanced according to 8 pc of potassium (K^+), 68 pc of calcium (Ca^{2+}) and 24 pc of magnesium (Mg^{2+}) [19];
- the minimum saturation level of exchangeable bases must be over 60 pc [19];
- the optimum C/N range is between 10 and 12 [20] [21].

2.4. Statistical Treatment of the Data

An analysis of variance (ANOVA) was performed, followed by identification of homogeneous groups of soils in healthy plots on the one hand and infested plots on the other (Newman Keuls test). The analysis of variance also involved the Student's T test, with a view to measuring the differences between the soils in healthy plots and those in diseased plots. All these analyses were carried out using XLSTAT software.

3. Results

3.1. Soil Acidity

Table 2 shows the soil pH values for the Bouaflé and Kononfla zones soils. The 0 - 20 cm layers of the Bouaflé soils have a similar acidity in healthy plots (pH = 6.6 - 6.9) and infested plots (pH = 6.2 - 6.5) ($P_{ANOVA} > 0.05$). The same observation was made at Kononfla. The pH in this part of the soils of the two types of plots is also similar in Bouaflé and Kononfla ($P_{Test-t} > 0.05$). At the level of the 20 - 40 cm layer, the soils of the same plot type were also identical in Bouaflé and Kononfla ($P_{ANOVA} > 0.05$). A difference was observed between soils in healthy plots and soils in infested plots in Bouaflé ($P_{Test-t} < 0.05$), unlike in Kononfla ($P_{Test} > 0.05$). The difference shows that soils in infested plots have a reaction close to neutrality, whereas soils in healthy plots are generally not very acidic.

Table 2. Variance of pH in soils.

Study zones	Soils layers	Plot types	Soils pH			Test ANOVA		Test T	
			Guessanfla soil	Krayaokro soil	Simporéfla soil	P	F	df	P
Bouaflé	0 - 20 cm	Healthy	6.5 ± 0.26a	6.2 ± 0.03a	6.5 ± 0.56a	0.56	0.70	9.65	0.68
		Infested	6.6 ± 0.03a	6.9 ± 0.45a	6.6 ± 0.00a	0.39	1.28		
	20 - 40 cm	Healthy	6.4 ± 0.03a	6.5 ± 0.31a	6.1 ± 0.10a	0.07	7.16	5.60	**0.00**
		Infested	6.9 ± 0.05a	6.6 ± 0.14a	6.6 ± 0.70a	0.68	0.43		
			Diénembroufla soil	Kayéta soil	Koumoudji soil	P	F	df	P
Kononfla	0 - 20 cm	Healthy	6.2 ± 0.02a	6.3 ± 0.08a	6.3 ± 0.03a	0.17	3.36	7.79	0.19
		Infested	6.2 ± 0.00a	6.2 ± 0.01a	6.2 ± 0.04a	0.82	0.20		
	20 - 40 cm	Healthy	6.3 ± 0.03a	6.3 ± 0.03a	6.2 ± 0.01a	0.11	4.86	7.84	0.22
		Infested	6.3 ± 0.02a	6.3 ± 0,03a	6.3 ± 0.04a	0.79	0.25		

- For ANOVA, means assigned the same letter on a line are identical. - For the T Test, the P values in bold in the table reflect a significant difference at the 5 pc threshold between the soils in healthy plots and in infested plots.

3.2. Soil Organic Carbon and Total Nitrogen

For all the soil layers explored, there was no significant difference between the soils of plots of the same type ($P_{ANOVA} > 0.05$) (Table 3) or between the soils of healthy plots and those of infested plots ($P_{Test-T} > 0.05$) (Table 4). In healthy plots, C levels were close to 1.00 pc in the 0-20 cm layer, equivalent to 1.72 pc of organic matter. In this layer, average N levels fluctuated around 0.08 pc. In the 20 - 40 cm layer, C and N levels in healthy plots are approximately one-third to one-half of the averages observed in the 0 - 20 cm layer.

3.3. Assimilable Soil Phosphorus

On all sites, the rates are similar for the same types of plots and for the same layers ($P_{ANOVA} > 0.05$) (Table 5). However, levels were higher in the 20 - 40 cm layers, especially in the healthy plots (0.82 g/kg). All in all, the levels remain below 1 g/kg and above 0.56 g/kg. Comparison of the soils of the two types of plots, across all the sites in Bouaflé and Kononfla, nevertheless revealed a significant difference between the soils ($P_{Test-T} < 0.05$) (Table 5).

Table 3. Variance of C and N levels in soils of the same plot types.

Study zones	Soils layers	Plot types	Soils variables	Soils levels (pc)			Test ANOVA	
				Guessanfla soil	Krayaokro soil	Simporéfla soil	P	F
Bouaflé	0 - 20 cm	Healthy	C	0.92 ± 0.17a	1.05 ± 0.07a	0.99 ± 0.31a	0.51	0.83
			N	0.07 ± 0.00a	0.08 ± 0.00a	0.08 ± 0.02a	0.73	0.33
		Infested	C	0.87 ± 0.17a	1.27 ± 0.24a	0.87 ± 0.53a	0.50	0.86
			N	0.07 ± 0.01a	0.12 ± 0.00a	0.08 ± 0.06a	0.44	1.07
	20 - 40 cm	Healthy	C	0.35 ± 0.00a	0.60 ± 0.28a	0.35 ± 0.00a	0.34	1.56
			N	0.03 ± 0.00a	0.05 ± 0.01a	0.03 ± 0.00a	0.17	3.34
		Infested	C	0.40 ± 0.14a	0.62 ± 0.03a	0.32 ± 0.31a	0.41	1.19
			N	0.03 ± 0.01a	0.05 ± 0.01a	0.02 ± 0.03a	0.49	0.88
				Diénembroufla soil	Kayéta soil	Koumoudji soil	P	F
Kononfla	0 - 20 cm	Healthy	C	0.93 ± 0.01a	0.83 ± 0.09a	0.90 ± 0.09a	0.53	0.78
			N	0.07 ± 0.00a	0.065 ± 0.00a	0.067 ± 0.00a	0.60	0.60
		Infested	C	0.90 ± 0.04a	1.01 ± 0.02a	0.84 ± 0.09a	0.13	4.16
			N	0.067 ± 0.00ab	0.075 ± 0.00a	0.062 ± 0.00a	0.61	0.65
	20 - 40 cm	Healthy	C	0.82 ± 0.05a	0.98 ± 0.06a	0.88 ± 0.01a	0.10	5.10
			N	0.06 ± 0.00a	0.07 ± 0.00a	0.06 ± 0.00a	0.18	3.16
		Infested	C	0.83 ± 0.01a	0.91 ± 0.15a	0.95 ± 0.12a	0.65	0.48
			N	0.063 ± 0.00a	0.067 ± 0.01a	0.070 ± 0.00a	0.72	0.35

- Means assigned the same letter on a line are identical. - P values in bold in the table reflect a significant difference at the 5 pc threshold between the soils in healthy plots and in infested plots.

Table 4. Variance of C and N levels in the soils of different types of plots at Bouaflé and Kononfla.

Soils layers	Soils variables	Test T			
		Bouaflé soils		Kononfla soils	
		df	P	df	P
0 - 20 cm	C (%)	9.78	0.75	9.65	0.68
	N (%)	9.65	0.68	7.70	0.20
20 - 40 cm	C (%)	8.20	0.29	9.46	0.60
	N (%)	6.48	0.06	9.27	0.54

- P values in bold in the table indicate a significant difference between soils at the 5 pc level.

Table 5. Variance in assimilable phosphorus levels in soils.

Study zones	Soils layers	Plot types	Soils levels (g/kg)			Test ANOVA		Test T	
			Guessanfla soil	Krayaokro soil	Simporéfla soil	P	F	df	P
Bouaflé	0 - 20 cm	Healthy	0.72 ± 0.00a	0.72 ± 0.10a	0.75 ± 0.00a	0.49	0.95	7.03	**0.02**
		Infested	0.68 ± 0.01a	0.70 ± 0.13a	0.66 ± 0.01a	0.59	0.43		
	20 - 40 cm	Healthy	0.82 ± 0.06a	0.75 ± 0.15a	0.68 ± 0.07a	0.71	0.29	7.09	**0.01**
		Infested	0.60 ± 0.07a	0.73 ± 0.01a	0.63 ± 0.00a	0.09	5.65		
			Diénembroufla soil	Kayéta soil	Koumoudji soil	P	F	df	P
Kononfla	0 - 20 cm	Healthy	0.63 ± 0.00a	0.69 ± 0.13a	0.68 ± 0.02a	0.47	0.97	7.53	**0.03**
		Infested	0.57 ± 0.03a	0.61 ± 0.17a	0.66 ± 0.01a	0.69	0.41		
	20 - 40 cm	Healthy	0.63 ± 0.02a	0.75 ± 0.13a	0.77 ± 0.05a	0.43	0.19	7.31	**0.03**
		Infested	0.59 ± 0.07a	0.63 ± 0.01a	0.66 ± 0.00a	0.19	5.65		

- For ANOVA, means assigned the same letter on a line are identical. - For the T Test, the P values in bold in the table reflect a significant difference at the 5 pc threshold between the soils in healthy plots and in infested plots.

3.4. Exchangeable Bases and CEC of the Soil

Table 6 displays the Ca^{2+}, Mg^{2+} and K^{+} levels as well as the measured CECs. Of all these variables, none significantly distinguishes soils in the same types of plots in Bouaflé ($P_{ANOVA} > 0.05$). In Kononfla on the other hand, the levels of Ca^{2+} and K^{+} differentiate the soils, the soils most supplied with Ca^{2+} being in healthy plots of Kayéta (64.44 ± 2.57 mmol(+)·kg^{-1}) and Diénembroufla (63.55 ± 1.27 mmol(+)·kg^{-1}), when the most supplied in K^{+} is the soil in the infested plot of the Koumoudji site (3.65 ± 0.05 mmol(+)·kg^{-1}).

Comparison of the soils of the two types of plots shows differences in the 0 - 20 cm layers in Bouaflé and 20 - 40 cm layers in Kononfla (Table 7). Indeed, in Bouaflé, the CEC and the Mg^{2+} rate are sometimes higher in healthy plots or in infested plots. In Kononfla, the difference observed is induced by Ca^{2+} with higher levels in healthy plots ($P_{Test\text{-}T} < 0.05$).

3.5. Chemical Balances and Saturation State of the Soil Adsorbent Complex

The balances between the exchangeable bases relative to their sum are worth 4 pc of K^{+} in all layers, 80 and 70 pc of Ca^{2+} between 0 - 20 and 20 - 40 cm from the ground, then approximately 15 and 25 pc of Mg^{2+} in layers 0 - 20 and 20 - 40 cm (Table 8). The exchangeable base saturation rates exceed 60 pc on all plots. Even if these variations in cationic equilibrium states between soils are not significant, both on the scale of the same types of plot ($P_{ANOVA} > 0.05$) and on the scale of plots of different typologies ($P_{Test\text{-}t} > 0.05$) (Table 9), we note overall that the greatest values of the variables come from the soils of healthy plots.

The balance between organic carbon and nitrogen indicated by the C/N ratio varies between 12 and 13 in the 0 - 20 cm layer, then 12 and 13 in the 20 - 40 cm layer (Table 8). These variations do not significantly distinguish soils from the same types of plots ($P_{ANOVA} > 0.05$) (Table 8), similarly for soils from different types of plots ($P_{Test-T} > 0.05$) (Table 9).

Table 6. Variance of the CEC and the exchangeable bases levels in the soils of the same types of plot.

Study zones	Soils layers	Plot types	Soils variables	Soils levels (mmol(+)·kg^{-1})			Test ANOVA	
				Guessanfla soil	Krayaokro soil	Simporéfla soil	P	F
Bouaflé	0 - 20 cm	Healthy	Ca^{2+}	62.18 ± 5.83a	53.13 ± 8.16a	60.60 ± 19.72a	0.76	0.29
			K^{+}	3.52 ± 0.67a	2.87 ± 0.81a	1.90 ± 0.28a	0.17	3.37
			Mg^{2+}	12.52 ± 1.02a	10.30 ± 2.75a	11.02 ± 0.95a	0.52	0.80
			CEC	71.63 ± 0.53a	66.00 ± 21.92a	59.75 ± 15.20a	0.76	0.29
		Infested	Ca^{2+}	57.49 ± 12.46a	54.28 ± 24.00a	54.10 ± 32.59a	0.32	1.66
			K^{+}	2.82 ± 0.24a	4.27 ± 1.23a	2.57 ± 0.38a	0.19	2.90
			Mg^{2+}	7.10 ± 0.07a	17.25 ± 6.64a	9.65 ± 3.81a	0.20	2.85
			CEC	66.00 ± 14.84a	118.75 ± 29.34a	60.00 ± 36.06a	0.21	2.63
	20 - 40 cm	Healthy	Ca^{2+}	52.06 ± 2.35a	76.03 ± 34.25a	56.58 ± 14.81a	0.45	1.05
			K^{+}	4.45 ± 0.28a	3.47 ± 0.45a	3.55 ± 2.12a	0.71	0.37
			Mg^{2+}	9.55 ± 1.48a	14.17 ± 1.52a	10.37 ± 5.62a	0.46	1.01
			CEC	58.13 ± 1.59a	84.25 ± 25.10a	61.25 ± 0.35a	0.28	1.93
		Infested	Ca^{2+}	63.64 ± 1.50a	53.80 ± 3.81a	46.70 ± 19.44a	0.43	1.09
			K^{+}	2.47 ± 0.81a	3.52 ± 1.02a	1.72 ± 1.37a	0.384	1.36
			Mg^{2+}	11.23 ± 5.49a	9.65 ± 2.40a	14.70 ± 11.59a	0.80	0.23
			CEC	68.75 ± 10.25a	59.50 ± 8.48a	47.25 ± 0.35a	0.14	3.94
				Diénembroufa soil	Kayéta soil	Koumoudji soil	P	F
Kononfla	0 - 20 cm	Healthy	Ca^{2+}	62.88 ± 0.04a	56.52 ± 9.13a	59.36 ± 6.75a	0.66	0.47
			K^{+}	3.29 ± 0.02a	3.16 ± 0.26a	3.44 ± 0.16a	0.39	1.28
			Mg^{2+}	22.34 ± 0.02a	20.10 ± 3.07a	21.10 ± 2.51a	0.66	0.48
			CEC	126.20 ± 20.1a	97.16 ± 19.4a	121.88 ± 3.0a	0.29	1.85
		Infested	Ca^{2+}	60.35 ± 3.07a	65.32 ± 2.17a	55.73 ± 2.87a	0.08	6.15
			K^{+}	3.34 ± 0.02a	3.27 ± 0.18a	3.34 ± 0.10a	0.81	0.22
			Mg^{2+}	22.40 ± 0.89a	22.71 ± 2.25a	20.91 ± 0.09a	0.48	0.94
			CEC	128.87 ± 18.0a	100.25 ± 13a	113.21 ± 24a	0.43	1.09
	20 - 40 cm	Healthy	Ca^{2+}	63.55 ± 1.27ab	64.44 ± 2.57b	66.67 ± 0.08a	**0.03**	13.14
			K^{+}	3.53 ± 0.01a	3.43 ± 0.19a	3.16 ± 0.12a	0.13	4.24
			Mg^{2+}	23.90 ± 0.14a	22.10 ± 2.10a	20.21 ± 1.52a	0.19	3.02
			CEC	94.93 ± 0.07a	114.38 ± 27a	112.92 ± 21a	0.61	0.57
		Infested	Ca^{2+}	50.37 ± 0.44a	60.70 ± 13.2a	67.79 ± 11.4a	0.35	1.49
			K^{+}	3.16 ± 0.05a	3.15 ± 0.16a	3.65 ± 0.05b	**0.02**	14.12
			Mg^{2+}	20.00 ± 1.00a	19.93 ± 2.91a	23.22 ± 4.43a	0.55	0.73
			CEC	95.37 ± 4.58a	123.15 ± 25.5a	106.08 ± 49.6a	0.71	0.37

- Means assigned the same letter on a line are identical. - P values in bold in the table reflect a significant difference at the 5 pc threshold between the soils in healthy plots and in infested plots.

Table 7. Variance of the CEC and exchangeable bases levels in the soils of the two types of plots in Bouaflé and Kononfla.

		Test T			
Soils layers	Soils variables	Bouaflé soils		Kononfla soils	
		df	P	df	P
0 - 20 cm	Ca^{2+}	6.50	0.06	9.63	0.67
	K^{+}	9.81	0.76	7.81	0.22
	Mg^{2+}	5.85	**0.01**	8.80	0.41
	CEC	6.27	**0.04**	9.98	0.92
20 - 40	Ca^{2+}	7.65	0.19	6.29	**0.04**
	K^{+}	9.94	0.08	9.24	0.53
	Mg^{2+}	7.80	0.22	8.85	0.42
	CEC	8.70	0.39	8.63	0.37

- P values in bold in the table reflect a significant difference at the 5 pc threshold between the soils in healthy plots and in infested plots.

Table 8. Variance of chemical balances in the soils of the same types of plots.

Study zones	Soils layers	Plots	Soils variables	Soils levels			Test ANOVA	
				Guessanfla soil	Krayaokro soil	Simporéfla soil	P	F
Bouaflé	0 - 20 cm	Healthy	SEB (mmol(+)·kg^{-1})	78.22 ± 4.13a	66.30 ± 6.22a	73.52 ± 19.05a	0.64	0.51
			Mg^{2+}/SEB	0.160 ± 0.02a	0.158 ± 0.05a	0.156 ± 0.05a	0.99	0.00
			Ca^{2+}/SEB	0.793 ± 0.03a	0.799 ± 0.04a	0.816 ± 0.05a	0.88	0.13
			K^{+}/SEB	0.045 ± 0.01a	0.042 ± 0.00a	0.026 ± 0.00a	0.17	3.30
			V (pc)	109.23 ± 6.58a	104.66 ± 25.32a	122.97 ± 0.60a	0.52	0.79
			C/N	12.87 ± 0.88a	13.00 ± 2.12a	12.37 ± 0.35a	0.44	1.06
		Infested	SEB (mmol(+)·kg^{-1})	67.41 ± 12.78a	115.80 ± 31.89a	66.32 ± 36.80a	0.29	1.89
			Mg^{2+}/SEB	0.107 ± 0.01a	0.146 ± 0.01a	0.153 ± 0.02a	0.21	2.63
			Ca^{2+}/SEB	0.85 ± 0.02a	0.81 ± 0.01a	0.80 ± 0.04a	0.41	1.21
			K^{+}/SEB	0.042 ± 0.00a	0.036 ± 0.00a	0.043 ± 0.01a	0.80	0.23
			V (pc)	102.55 ± 3.70a	97.16 ± 2.84a	112.41 ± 6.22a	0.09	5.92
			C/N	12.50 ± 0.70a	10.00 ± 2.12b	11.75 ± 3.18a	0.07	7.21
	20 - 40 cm	Healthy	SEB (mmol(+)·kg^{-1})	90.99 ± 1.14a	89.98 ± 4.86a	80.05 ± 1.55a	0.06	7.99
			Mg^{2+}/SEB	0.26 ± 0.00a	0.24 ± 0.01a	0.25 ± 0.01a	0.37	1.40
			Ca^{2+}/SEB	0.69 ± 0.00a	0.71 ± 0.01a	0.70 ± 0.01a	0.37	1.39
			K^{+}/SEB	0.038 ± 0.00a	0.038 ± 0.00a	0.039 ± 0.00a	0.13	4.16
			V (pc)	95.85 ± 1.13a	81.50 ± 23.69a	72.39 ± 15.44a	0.45	1.04
			C/N	11.00 ± 0.00a	10.00 ± 1.41a	10.50 ± 0.70a	0.60	0.60
		Infested	SEB (mmol(+)·kg^{-1})	73.53 ± 0.61a	83.79 ± 16.35a	94.67 ± 15.81a	0.39	1.29
			Mg^{2+}/SEB	0.27 ± 0.01a	0.23 ± 0.01a	0.24 ± 0.00a	0.08	6.04
			Ca^{2+}/SEB	0.68 ± 0.01a	0.72 ± 0.01a	0.71 ± 0.00a	0.09	5.47
			K^{+}/SEB	0.042 ± 0.00a	0.038 ± 0.00a	0.039 ± 0.00a	0.66	0.47
			V (pc)	77.21 ± 4.35a	68.13 ± 0.85a	96.32 ± 30.19a	0.38	1.33
			C/N	12.00 ± 0.70a	11.75 ± 1.76a	12.25 ± 1.76a	0.94	0.06

Continued

				Diénembroufla soil	Kayéta soil	Koumoudji soil	P	F
Kononfla	0 - 20 cm	Healthy	SEB (mmol(+)·kg⁻¹)	88.52 ± 0.04a	79.79 ± 12.47a	83.91 ± 9.10a	0.65	0.48
			Mg^{2+}/SEB	0.252 ± 0.00a	0.252 ± 0.00a	0.251 ± 0.00a	0.82	0.21
			Ca^{2+}/SEB	0.710 ± 0.00a	0.708 ± 0.00a	0.707 ± 0.00a	0.63	0.53
			K^{+}/SEB	0.037 ± 0.00a	0.039 ± 0.00a	0.041 ± 0.00a	0.63	0.52
			V (pc)	71.05 ± 11.39a	85.12 ± 29.91a	68.77 ± 5.72a	0.67	0.44
			C/N	13.25 ± 0.24a	12.74 ± 0.01a	13.24 ± 0.76a	0.52	0.80
		Infested	SEB (mmol(+)·kg⁻¹)	86.10 ± 3.99a	81.31 ± 4.62a	79.99 ± 2.67a	0.13	4.33
			Mg^{2+}/SEB	0.260 ± 0.00a	0.248 ± 0.01a	0.261 ± 0.00a	0.39	1.27
			Ca^{2+}/SEB	0.70 ± 0.00a	0.71 ± 0.01a	0.69 ± 0.01a	0.29	1.88
			K^{+}/SEB	0.038 ± 0.00a	0.035 ± 0.00a	0.041 ± 0.00a	0.09	5.60
			V (pc)	67.69 ± 12.55a	72.23 ± 17.07a	72.66 ± 18.2a	0.39	1.28
			C/N	13.34 ± 0.05a	13.48 ± 0.35a	13.42 ± 0.70a	0.95	0.05
	20 - 40 cm	Healthy	SEB (mmol(+)·kg⁻¹)	90.99 ± 1.14a	89.98 ± 4.86a	80.05 ± 1.55a	0.06	7.99
			Mg^{2+}/SEB	0.26 ± 0.00a	0.24 ± 0.01a	0.25 ± 0.01a	0.37	1.40
			Ca^{2+}/SEB	0.69 ± 0.00a	0.71 ± 0.01a	0.70 ± 0.01a	0.37	1.39
			K^{+}/SEB	0.038 ± 0.00a	0.038 ± 0.00a	0.039 ± 0.00a	0.13	4.16
			V (pc)	95.85 ± 1.13a	81.50 ± 2369a	72.39 ± 15.44a	0.45	1.04
			C/N	13.00 ± 0.16a	13.12 ± 0.34a	13.03 ± 0.45a	0.94	0.06
		Infested	SEB (mmol(+)·kg⁻¹)	73.53 ± 0.61a	83.79 ± 16.35a	74.67 ± 15.81a	0.39	1.29
			Mg^{2+}/SEB	0.27 ± 0.01a	0.23 ± 0.01a	0.24 ± 0.00a	0.08	6.04
			Ca^{2+}/SEB	0.68 ± 0.01a	0.72 ± 0.01a	0.71 ± 0.00a	0.09	5.47
			K^{+}/SEB	0.042 ± 0.00a	0.038 ± 0.00a	0.039 ± 0.00a	0.66	0.47
			V (pc)	77.21 ± 4.35a	68.13 ± 0.85a	76.32 ± 30.19a	0.38	1.33
			C/N	13.14 ± 0.03a	13.40 ± 0.24a	13.51 ± 0.43a	0.51	0.83

- Means assigned the same letter on a line are identical. - P values in bold in the table reflect a significant difference at the 5 pc threshold between the soils in healthy plots and in infested plots.

Table 9. Variance of chemical balances in the soils of the two types of plots in Bouaflé and Kononfla.

		Test T			
Soils layers	Soils variables	Bouaflé soils		Kononfla soils	
		df	P	df	P
0 - 20 cm	SEB (mmol(+)·kg⁻¹)	5.97	0.49	9.21	0.67
	Mg^{2+}/SEB	9.38	0.24	5.20	0.27
	Ca^{2+}/SEB	9.80	0.35	5.53	0.43
	K^{+}/SEB	9.60	0.63	9.61	0.74
	V (pc)	7.64	0.25	9.99	0.79
	C/N	9.00	0.26	9.57	0.64

Continued

20 - 40 cm	SEB (mmol(+)·kg^{-1})	8.50	0.71	6.74	0.64
	Mg^{2+}/SEB	9.98	0.90	8.51	0.85
	Ca^{2+}/SEB	9.92	0.76	7.97	0.97
	K^{+}/SEB	9.55	0.25	5.23	0.52
	V (pc)	6.22	0.38	9.83	0.79
	C/N	8.59	0.36	9.98	0.08

- P values in bold in the table reflect a significant difference at the 5 pc threshold between the soils in healthy plots and in infested plots.

4. Discussion

In this study, the soil variables evaluated are, on the one hand, the levels of C, N, P and exchangeable bases including Ca^{2+}. Acidity (pH), CEC and chemical equilibrium states in the soils were also evaluated. Only acidity and Ca^{2+} and P levels marked significant differences between the soils of healthy plots and those of infested plots with a very specific trend for the soils of each type of plot. These differences were generally characteristic of the 20 - 40 cm layer of soil. Furthermore, in Bouaflé, the CEC and the Mg^{2+} rate, sometimes being higher in healthy plots or in infested plots, are difficult to interpret.

The acidity of the soil effectively distinguished the soils in Bouaflé, precisely the 20-40 cm layers. These layers appeared slightly acidic in the soils in healthy plots while they were close to neutral in the soils in infested plots. This result was not repeated in Kononfla. Likewise, according to their Ca^{2+} levels in the 20 - 40 cm layer, the soils appeared different only in Kononfla, with higher levels in the soils in healthy plots. The phosphorus levels differentiated between all the soil layers in Bouaflé and Kononfla. The richest soils were those observed in healthy plots. These results demonstrate that the chemical quality of the soil can influence the prevalence of swollen shoot in cocoa trees. A ground depth effect can also be mentioned.

In cocoa farming, cultivation practices can modify soil fertility potential. This is particularly true of weeding, shade tree management and mineral or organic fertilisation. Associated crops or shade trees can modify soil fertility potential, either by bringing in nutrients from outside, or by competition for elements in the crop association [22]. In the study area, farmers with generally similar farming practices will have soils with similar chemical characteristics in the topsoil, estimated here as the top 20 cm of soil. This is not obvious for the deeper soil layers, which are little affected by farming practices, hence the differences observed in the 20 - 40 cm soil layers.

In the study carried out by [9], which aimed to assess the morphological properties of soils under cocoa trees affected by swollen shoot, a soil depth effect was also observed on the prevalence of the disease. In fact, the authors concluded that the disease generally appeared in cocoa farms when mechanical obstacles were present at a depth of 50 to 70 cm, in this case the occupation of a large volume of soil by ferromanganic concretions (at least 50 pc of the soil volume), hydromorphy and soil compaction.

The acidity of the soils (pH ranging from 4.98 to 5.63) was clearly not a constraint for the cocoa tree, since the soils in the healthy plots were slightly acidic, unlike the soils in the diseased plots, which were slightly neutral. As healthy plots are in production, their soils are often treated with chemical fertilisers to increase yields. In the long and medium term, this has the effect of acidifying the soil [22]. But as long as the pH remains above 4.5 or below 8, production is not as negatively affected as it could be [23].

In addition to the positive effect they have on cocoa productivity, the nutrients provided by fertilisation or naturally present in the soil also improve disease resistance and fruit quality and vigour. For example, according to [24], cocoa trees deficient in Ca^{2+} and Mg^{2+} are less resistant to pod rot, but also to other diseases such as swollen shoot, given the results obtained in this research.

The low concentration of phosphorus in the soil solution is usually adequate for normal plant growth. Indeed, [25] suggests that a concentration of 0.2 ppm phosphorus is adequate for optimal plant growth. In tropical soils, which are genetically poor in this element [26] [27], but also because in these soils the abundance of secondary minerals such as iron and aluminium oxides are conducive to strong retention of phosphate ions, limiting their availability [28], a small variation in P can be enough to induce a significant difference in crop development or disease resistance. This is the main reason for the positive correlation observed between the disease and low P levels. These low levels appear to be the main chemical factor explaining the presence of the disease, as they were the only findings in both soils in infested plots in the two sectors of the study area.

Considered with nitrogen (N) and potassium (K) as the fundamental constituents of plant and animal life, but also as the major nutrient elements of plants, phosphorus (P) plays a role in a whole series functions of plant metabolism. Indeed, it has structural functions in macromolecules such as nucleic acids and energy transfer functions in metabolic pathways of biosynthesis and degradation [29]. When these functions are limited by a P deficiency in the soil, the cocoa tree can be made vulnerable to all kinds of pathologies such as swollen shoot.

5. Conclusion

The study carried out showed that when soils are characterized between 20 and 40 cm depth by relatively high levels of P and Ca^{2+} and by low acidity, swollen shoot is non-existent in cocoa trees. Low P levels would constitute the main chemical constraints which explain the appearance of the disease in cocoa trees. Previous work having called into question certain morphological properties of the soil, leads us to believe that any fight against swollen shoot of the cocoa tree which is intended to be sustainable must integrate the soil, the natural support of the plant. Also, to draw a more complete conclusion on the role of soil in the prevalence of the disease, it would be necessary to inventory the soil microorganisms involved and determine their roles and, also, extend the study to other endemic areas for a confirmation or clarification of the conclusions emerging from the present study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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