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ANALYSIS OF THE MORPHO-PEDOLOGICAL CHARACTERISTICS OF SOILS UNDER COCOA ORCHARDS AFFECTED BY SWOLLEN-SHOOT IN BOUAFLE (CENTRAL-WEST IVORY COAST)

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ABSTRACT

The agricultural sector, in particular cocoa production, plays a key role in the socioeconomic development of Côte d'Ivoire. With climate change, soil impoverishment and diseases such as swollen-shoot, we are witnessing a drop in production, leading to the decline of many orchards. Since the various attempts to find solutions to this problem have all ended in failure, and even though these attempts have generally never overlooked the soil as a natural support for plants, the overall aim of this study is to diagnose the prevalence of swollen-shoot disease in the soil. A morpho-pedological study was carried out in the Bouaflé department in the Marahoué region, the main endemic area in Côte d'Ivoire, to compare the characteristics of soils under healthy orchards with those under infested orchards. The main differences observed were a higher load of ferruginous concretions and poor internal drainage of soils in diseased plots. While waiting to explore the chemical properties of soils, these results lead to the conclusion that the appearance of the disease in cocoa trees also depends on the quality of the cultivation soil.

Keywords: Swollen-shoot, Cocoa Tree, Soil, Morphology, Ivory Coast.

1. INTRODUCTION

The agricultural sector, particularly cocoa farming, plays a key role in the economic and social development of many African countries (Benin, Ivory Coast, Togo, Ghana and Nigeria) (Jagoret, 2011). Africa even holds the monopoly on cocoa production, with more than 70 pc of the global supply (Wessel and Quist Wessel, 2015). With production totalling 1.7 million tonnes, or 42 pc of global supply, Côte d'Ivoire is the world's leading producer (ICCO, 2015).

The areas of highest production were initially the east and centre-east of Côte d'Ivoire, which then formed the cocoa loop. With climate change, soil impoverishment and other constraints on cocoa farming, the cocoa loop has moved to the west of the country, driven by migratory flows. Today, with over 36pc of national production, the main cocoa-growing area in Côte d'Ivoire is the Centre-West, which includes the administrative region of Marahoué. Unfortunately, cocoa farming in this region is under serious threat from the Swollen shoot disease, which is causing very significant reductions in yields.

This viral disease is transmitted by mealybugs of the Pseudococcidae family, the most virulent isolate of which (Agou 1) causes intense red discolouration of young leaves, discolouration of adult leaves, swelling of stems and twigs and stunting of pods. Various methods have been put in place to combat the virus, but to no avail. These include uprooting (Ollennu et al., 1989), chemical and biological vector control (Entwistle, 1958), premunition (Ollennu et al., 1996), the use of cordon sanitaire and barrier crops (Fofie et al., 2003) and the selection of resistant varieties (Adu-Ampomah et al., 2003 ; Dogbé et al., 2006). These efforts have not yet neglected the soil, the natural support of the cocoa orchard, leading us to believe that edaphic factors condition the vulnerability of the cocoa tree to the swolen-shoot virus. This research has come at the right time to shed light on this issue.

The overall aim is to establish a soil diagnosis of the prevalence of the swollen shoot disease, which inevitably involves: i) determining the morphological properties of soils under orchards of cocoa trees affected by swollen shoot and soils under orchards of healthy cocoa trees; ii) comparing the properties of the two categories of soil.

2. MATERIALS AND METHODS

2.1. Presentation of the study area

The study was carried out in the department of Bouaflé, capital of the Marahoué region in Côte d'Ivoire (West Africa). It was carried out at three sites : 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") (Figure 1). These different localities are part of the department's cocoa production zones that are heavily affected by swollen-shoot disease.

The region straddles the divide between the sub-equatorial Atean climate and the humid tropical Baulean climate. It is characterised by two main seasons alternating with two short ones. The long rainy season begins in March and ends in June, while the short rainy season runs from mid-August to October. Between the two rainy seasons is the short dry season from July to mid-August, while the long dry season runs from November to February (N'guessan*et al*., 2012).

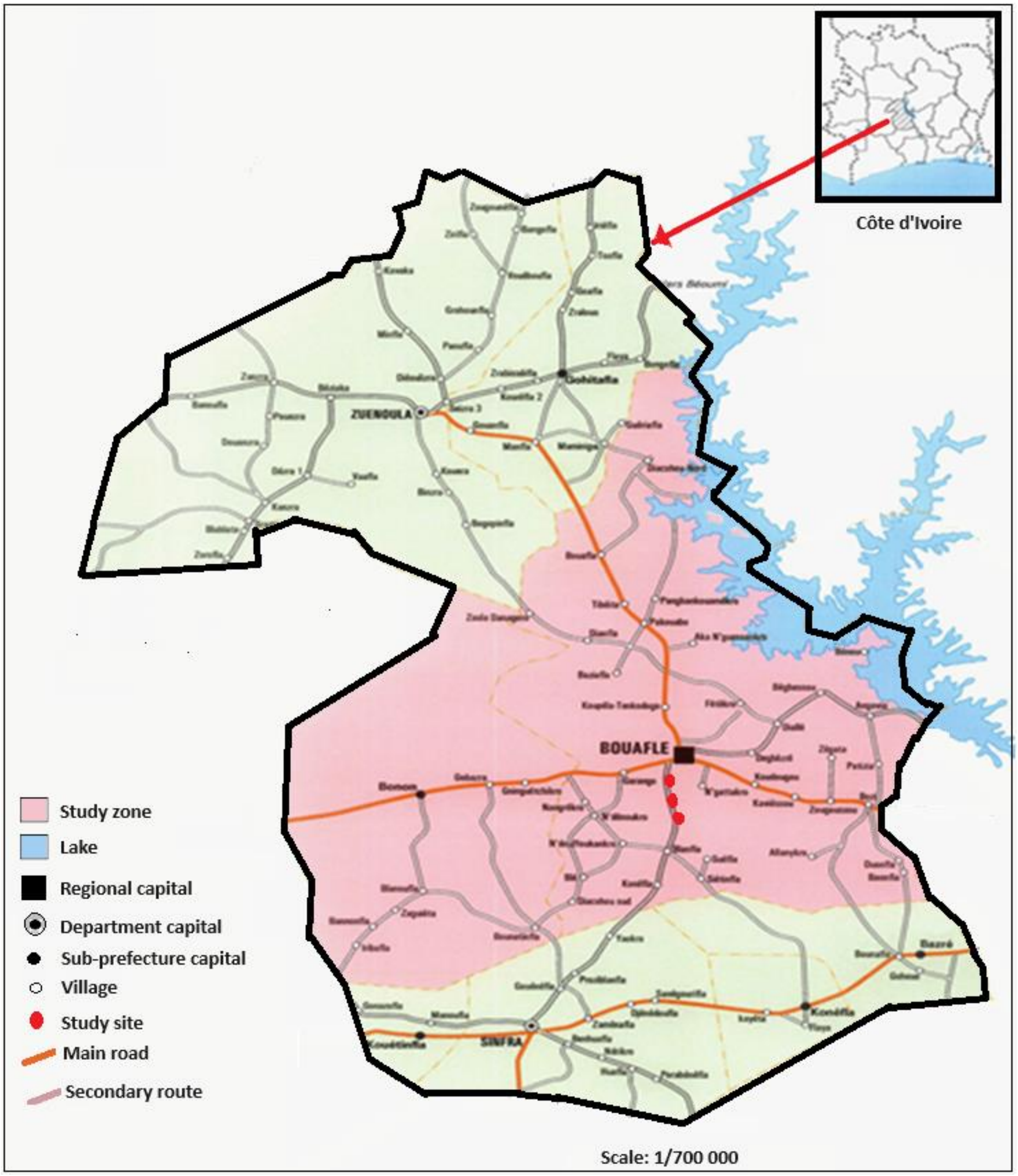

Figure 1 : Map showing the location of the study area.

Annual rainfall is between 1,800 and 2,000 mm ; the average annual temperature is around 25.30°C, with an average humidity of 75 pc. It is a transitional climate between savannah and forest, very favourable to farming and livestock rearing (Douka, 2012). The area is drained by

the Bandama rouge or Marahoué river and the Bandama blanc (N'guessan et al., 2017). It is a transition zone between dense forest and wooded savannah, two types of plant formation which, depending on the dominance of one over the other, are distributed to the south and south-west for the dense forest, then to the north and north-east for the wooded savannah (Douka, 2012).
The relief of the region is therefore relatively flat, consisting of low plateaux with a few shallows in the plains and hills with an average altitude of 260 m (Douka, 2012). Geologically, the area belongs to the Birrimian granite and schist group (Leneuf and Tempier, 1969). The soils are generally Ferralsols (Eutric), with slightly different characteristics depending on whether you are in the forest or the savannah. There are also pockets of Acrisols in the north and northeast of the zone, and Gleysols on the riverbanks (Douka, 1981).

2.2 Data collection

2.2.1. Experimental set-up

The soil survey is carried out according to the slope of the land, determined using a clisimeter. When the topography of the plantation is virtually flat (slope ≤ 8 pc) and the cultivation history of the plantation is identical throughout, the state of vigour of the vegetation (growth, development and health status, weed or pest infestation) is generally a better reflection of the nature of the underlying soil (Freschet et al., 2018). The soil pits (three in total per site) are then placed in the working plot in a sequence determined by the diversity observed in the plant cover (Figure 2). On the other hand, if the plot is characterised by a significant slope (slope > 8 pc), the location of the soil pits on the working plot is guided by the toposequence method based on the principle that there is a close relationship between the shape of a region (morphology) and the different types of soil described (pedology) (Lévêque, 1972). The morpho-pedological study was then carried out along a line perpendicular to the contour lines: the three pits were placed on a transect along the toposquence, with one pit positioned at the top of the slope, another at mid-slope and the last pit at the bottom of the slope.

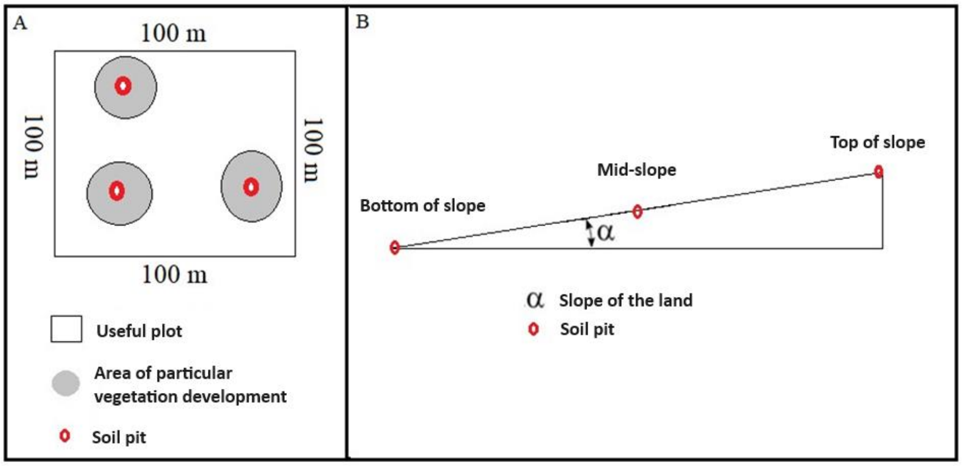

Figure 2 : Arrangement of soil pit locations
A : according to the vigour of the plant cover ; B : according to the toposequence..

2.2.2. Opening of soil pits and description of soil morphology

Each pit was opened so that it was 120 cm deep, 100 cm long and 100 cm wide respectively, provided there were no impassable obstacles, particularly in terms of depth. To avoid compacting the soil around the edges of the pits, the soil removed was placed on one side of the pit only (to the right or left of the observation face) (Figure 3).

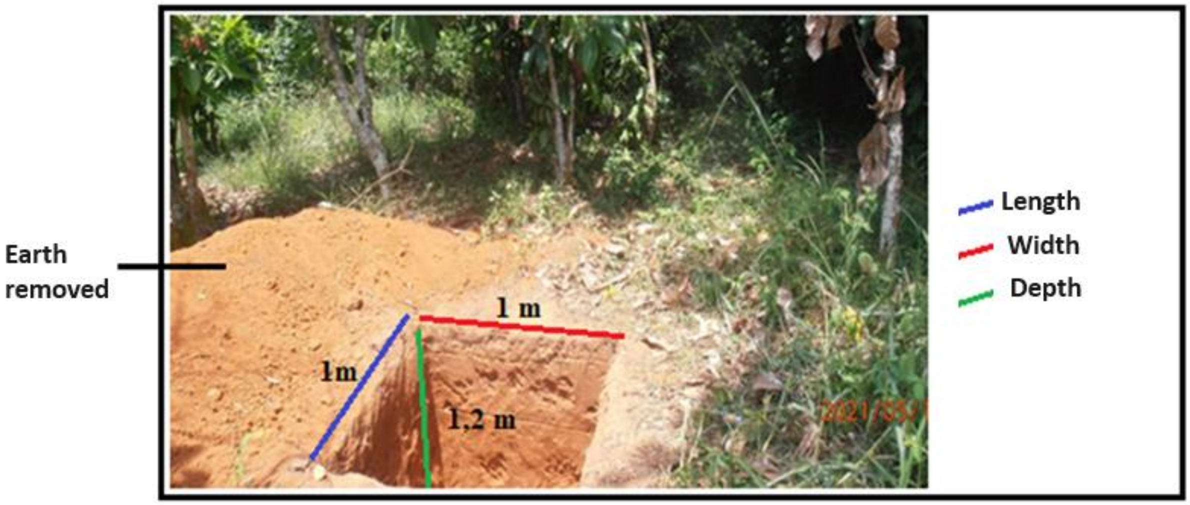

Figure 3 : Soil pit

Observations in each pit consisted of identifying the different horizons (visually or using a soil knife) and determining, for each horizon :

- the thickness using a decameter ;
- colour using the Munsell code;
- the texture by tactile means, by making a ring of moist soil and a ring with the ring: the soil is more clayey when the ring is easy to form and sandy when it is impossible to form it; the texture was also determined in the laboratory;
- the general structure of the soil and that of the flow by visual observation of the faces of a soil sample taken and broken into pieces;
- the compactness and general cohesion of the horizon measured by the penetration test, which consists of pushing a soil knife into the horizon and estimating the ease with which the knife penetrates the soil: the soil is more compact when the operator exerts more effort;
- the presence of organic matter in the soil by visual observation: the horizon is more humus-bearing when it is darker in colour;
- the porosity and permeability of the horizon by assessing the infiltration speed of a drop of water deposited on a lump of soil, the soil being more permeable when water infiltrates more quickly;
- the quality of soil drainage by locating and counting spots of pseudogley rust on the horizon caused by water stagnation;
- the depth at which the hydromorphic top appears (PATH) using a decameter; - the rate of coarse elements by the following formula 1 :

$$EG\ (pc) = (MR/MT)\ x100\ (1)$$

Where : MT = Mass in grams of the dried sample and MR = Mass in grams of the dried soil reject after sieving.

2.3 Statistical processing of data

The normality of the distributions of the samples and the homogeneity of their variances were verified by the Shapiro-Wilk and Levène tests respectively. When the variable from which the sample is drawn follows a normal distribution and the variances are homogeneous, an ANOVA is performed. Otherwise, the non-parametric Kruskal-Wallis test is applied. The analysis of variance also involved the Student's T TEST, which was used to measure the differences, at landscape level, between the means of the soil variables for the two types of plots studied (healthy plots and diseased plots). All analyses were carried out using R software version 3.6.3.

3. RESULTS

3.1. Morpholo-pedological characteristics of soils

The open soil profiles on all the sites, in both healthy and diseased plots, generally have the same level of profile development (Figure 4). In fact, the soils are all very deep (at least 120 cm) and highly differentiated in terms of horizons. These soils are also characterised by total alteration of the primary minerals. The surface horizons are humus-bearing, generally not very developed (10 to 30 cm) and coloured dark brown (7.5YR 5/6 to 7.5YR 7/2) or reddish brown (5YR 3/3 to 5YR 4/4). Their overall structure is lumpy and their texture is sandy-clayey to the touch. The buried horizons are thicker (over 40 cm) with a wide range of colours (reddish yellow: 7.5YR 6/8 to 7.5YR 7/6; red: 2.5YR 3/6 to 2.5YR4/6 and reddish brown 5YR 4/3). In this part of the soil, the texture is clayey-sandy or silty-sandy to the touch, when the overall structure is massive with a polyhedral flow.

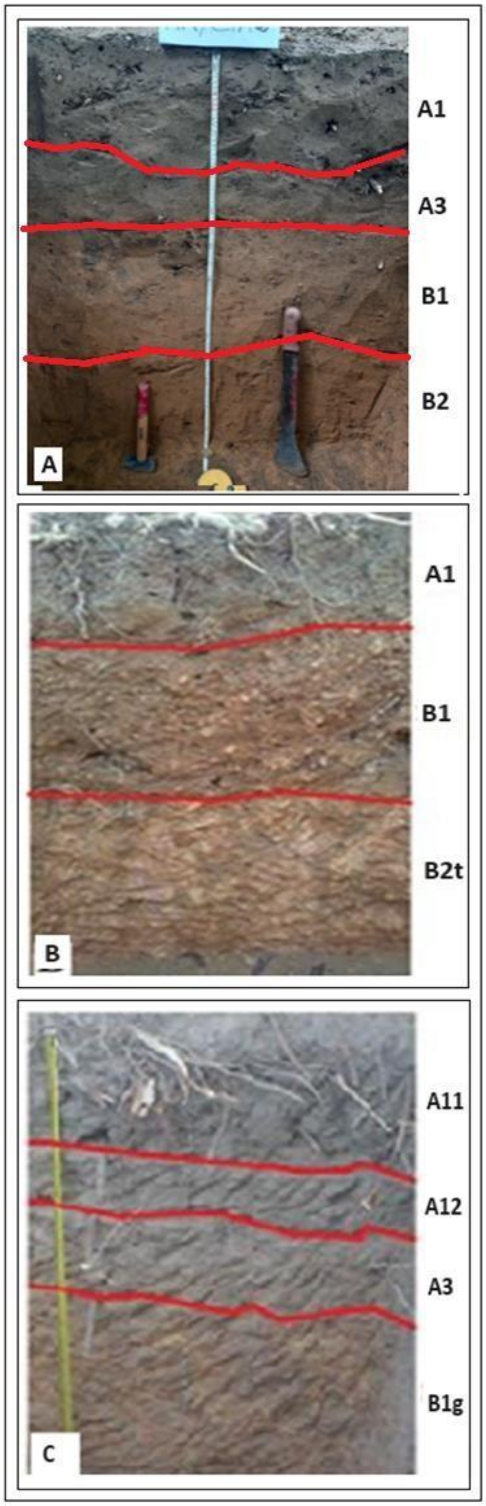

Figure 4 : Some soil profiles

- *A-Deep, well-drained soil with almost no coarse matter in a healthy plot at Simporéfla ;*
- *B-Deep soils, with a B1 horizon loaded with coarse elements and a B2t horizon compacted by Guessanfla clay ;*

- *C- Deep soils, with a B1g horizon showing traces of temporary hydromorphy at Guessanfla.*

3.2. Granulometry

- **Coarse elements**

In the Bouaflé plots, specifically those at Krayaokro and Guessanfla, the soils are characterised by moderately high loads of ferruginous chippings (50 to just over 60 pc) between 20 and 40 cm depth, whereas in the overlying horizon (0-20 cm), these levels are low (< 30 pc) (Table I). The Simporéfla soils, on the other hand, are almost devoid of these coarse elements. Overall, all the soil layers in the healthy plots differ from one another (*Anova* < 0.05). The same is true for all soil layers in infested plots. The opposite observation was made when the soils of the healthy plots were compared with those of the diseased plots in this locality (*TestT* > 0.05).

Table I : Concretion rates in soils

		Concretion rate in pc			*ANOVA*		*TEST-T*	
Layers	Plots	Guessanfla	Krayaokro	Simporéfla	*P*	F	df	*P*
0-20	Healthy	20.83±9.82ab	29,70±4,61b	0,00±0,0 a	0,03	11,84	9,98	0,93
	Patients	23.99±11.31ab	29,48±4,05b	0,00±0,0 a	0,04	10,22		
20-40	Healthy	50.40±23.75ab	66,67±0,04b	0,00±0,0a	0,03	12,84	9,99	0,95
	Patients	63,55±0,00b	59,13±9,66b	0,00±0,0a	0,00	80,87		

- **Fine elements**

Tables II and III show the proportions of the different fractions of sand, silt and clay found in the soil at the sites. In the 0-20 cm layers, the soils are much richer in sand (generally more than 50 pc). Clays (25 to 40 pc) and silts (19 to 31 pc) follow respectively. In the 20-40 cm layers, there is an accumulation of clays, with rates reaching over 38 pc in the healthy plots and 56 pc in the diseased plots. These rates, specifically the rates of clay and sand in the 20-40 cm layers, show significant differences between the soils of the healthy plots on the one hand and the soils of the infested plots on the other (*Test-T* < 0.05). The opposite was true between plots of the same type (*Anova* > 0.05).

Table II : Test Anova test of soil textures

			Floors			ANOVA	
Layers (cm)	Plots	Textures (pc)	Guessanfla	Krayaokro	Simporéfla	*P*	F
0-20	Healthy	Clay	24,75±6,71a	25,25±5,30a	15,75±7,42a	0,38	1,34
		Silt	23,62±1,23a	24,75±2,47a	19,00±2,82a	0,16	3,56
		Sand	51,62±7,95a	49,50±7,77a	65,00±4,94a	0,20	2,86
	Patients	Clay	26,88±9,36a	41,00±5,65a	20,50±19,09a	0,37	1,36
		Silt	24,25±3,18a	30,00±0,70a	20,75±20,75a	0,13	4,12
		Sand	48,63±12,90a	28,75±4,59a	59,25±23,68a	0,29	1,92
20-40	Healthy	Clay	34,62±6,89a	31,50±9,19a	38,25±11,66a	0,80	0,22
		Silt	26,75±0,35a	31,00±2,82a	21,50±0,70a	0,12	4,44
		Sand	38,37±7,60a	37,25±6,71a	40,25±13,08a	0,69	0,41
	Patients	Clay	56,00±7,77a	40,75±1,06a	23,75±18,03a	0,14	4,04
		Silt	21,00±14,14a	20,50±0,00a	22,75±3,88a	0,36	1,46
		Sand	22,91±48,79a	38,75±1,06a	53,50±21,92a	0,79	0,25

Table III : *T-TEST* of soil textures

Layers (cm)	Textures	df	*P*
0-20	Clay	7,45	0,16
	Silt	8,70	0,39
	Sand	7,35	0,15
20-40	Clay	7,06	0,01
	Silt	5,80	0,11
	Sand	6,03	0,02

3.3. Depth at which the hydromorphic top appears in the profiles

Across all sites, soils in diseased plots showed three times more evidence of deep hydromorphy than soils in healthy plots (Table IV and V). However, the frequency of occurrence of hydromorphy in the profiles was not significantly different (*TEST-T > 0.05*) (Table V). In contrast, the depths at which hydromorphy appeared were different (*ANOVA < 0.05*), but only in the soils of the diseased plots, where 50 or 55 cm were measured in some places and over 120 cm in others (Table VI).

Table IV : Frequency of occurrence of hydromorphy in soils between 0 and 120 cm

Condition of plots	Total number of soil pits	Frequency of occurrence of hydromorphy	Percentage of pits showing hydromorphy
Healthy	9	1	11,11
Patients	9	3	33,33

After transforming the percentages of occurrence of hydromorphy in the plots by the function GoF(X), G(x) corresponding to the Arcsin function and F(x) to the square root function, we obtain the following analysis of variance presented in Table V :

Table V : Average rates of occurrence of hydromorphy in plots

Healthy plots	Diseased plots	*TEST-T*	
		P	F
0,11± 0,19	0,33± 0,57	0,60	0,32

Table VI : Depths of appearance of the hydromorphic roof (PATH) in the first 120 cm of soil

Plots	PATH			*ANOVA*		*TEST-T*	
	Guessanfla	Krayaokro	Simporéfla	*P*	F	df	*P*
Healthy	> 120±00a	> 120±00a	> 120±00a	0,33	1	8	0,08
Patients	> 120±00a	55±00a	50±10b	0,00	147		

4. DISCUSSION

With regard to the good conditions to be observed in cocoa farming (CNRA, 2015 ; Koko, 2014), the edaphic conditions in terms of the morphology of the soils studied are generally favourable. However, their great depth is counteracted in the infested plots by a shallow depth of appearance, not only, of the moisture roofs (PATH) and horizons highly supplied with coarse elements, but also, by the accumulation of clays in the 20-40 cm layers.

The presence of a temporary hydromorphic horizon at shallow depths is an obstacle to the rooting of hydromorphic-sensitive plants such as cocoa. It occurs when the deep horizons are clayey or have continuous structures (soil compaction). In this case, rainwater drains very slowly and stagnates in the upper layers of the soil, creating excess water. This excess water constitutes a hydric obstacle to the rooting of many crops because of the hypoxic conditions created in the soil (Concaret, 1981).

The high loads of coarse elements made up of rubble or ferromanganic concretions that generally appear in Ferralsols reflect the reworking of the soil. According to Schwartz & Lanfranchi (1990), remodelling generally results from the lateral transport of materials by colluvium, ablation, aeolian contributions, anthropogenic disturbances and biological mixing. These coarse elements favour soil bearing capacity, soil aeration and soil infiltration capacity. On the contrary, their effects on agronomic fertility are unfavourable: in particular, they reduce the soil's water reserve, the use of tillage tools and encourage the leaching of nutrients from the soil (Delaunois, 2013). In addition, the presence of high loads of coarse elements in the soil can be an inhibiting factor for root penetration into the soil (Boyer, 1982). On this point in particular, a number of converging observations suggest that a limit of around 50 pc in relation to the weight of the soil, i.e. around 75 pc in relation to its volume, is reached at which point it is very difficult for roots to penetrate and develop within this horizon (Boyer, 1982).

The accumulation of clays observed in the 20-40 cm layers of certain soils in diseased plots, with rates reaching 50 pc in places, is the result of leaching from the upper layer. This can lead to poor water drainage in the accumulation layer, resulting in hypoxic conditions. Forestier (1964) believes that these conditions can lead to physiological disorders in plants, notably potassium deficiency associated with toxic doses of magnesium and sodium. These disorders could explain the appearance of swollen-shoot in cocoa plantations.

In short, the coarse elements and shallow hydromorphy create disturbances in the mineral and water nutrition of the cocoa tree, making the plant vulnerable to various physiological disorders such as swollen shoot. This would explain the observations according to which these two edaphic factors recurrently appear as the main degrading conditions in cocoa farming (Yoro, 2004 ; Koko *et al*., 2006 ; Kacou, 2023).

5. CONCLUSION

The soils explored were generally Ferralsols. The main differences observed between the soils of the infested plots and those of the healthy plots, although not always significant, were a higher load of ferruginous concretions and poor internal drainage in the soils of the diseased plots. These constraints, which appear at shallow depths, constitute mechanical obstacles preventing the exploration of a greater volume of soil by plant roots. As a result, cocoa trees are malnourished and vulnerable to all kinds of pathologies, including swollen-shoot. Soil fertilisation could be used to combat this disease more effectively. But before drawing any more comprehensive conclusions, we need to investigate how the chemical properties of the soil also impact on the prevalence of the disease in cocoa farms.

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