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Physical-Chemical Characteristics of Three Soils and Their Effects on the Growth and Nutritional Status of Coffee Trees

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The conversion of fallow land for the establishment of new orchards is now an alternative to Ivorian coffee growing, which has long been based on the extensive and shifting cultivation system favoured in the past by the abundance of forest reserves.
Study Design: Thus, three fallow soils under coffee trees were studied from a physical-chemical point of view in order to determine their potential for the productivity of new coffee varieties (*Coffea canephora* Pierre, var. Robusta).

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Place and Duration of Study: The study was conducted on the National Centre of Agriculture Research (CNRA) research station at Abengourou, Divo and Man for six months, between June and November.

Methodology: Soil samples and coffee leaves were collected and analyzed in the laboratory according to standard methods to determine their chemical status. Plant growth (height, crown diameter, number of orthotropic, number and length of plagiotropic internodes) was studied in relation to the physical-chemical characteristics of the soil.

Results: The chemical potential of the soils was found to be low overall. Soil deficiency was characterized by low base saturation (less than 30%), organic matter, nitrogen and cation imbalance, as regard as potassium (K), calcium (Ca) and magnesium (Mg). Growth parameters of the coffee trees and their nutritional status were correlated with the physicochemical properties of the soil.

Conclusion: In view of these results, sustainable coffee production requires an improvement in the level of soil fertility under coffee trees.

Keywords: Chemical potentials; growth and nutritional status; coffee trees; ferralsol fallows.

1. INTRODUCTION

The selection and development of new and more efficient coffee varieties with yields above 2 tons/ha/year marketable coffee [1] require fertile soils to express their full potential. In the past, forest reserves that allowed farmers to practice extensive coffee cultivation without worrying about soil fertility are no longer available [2]. In the various coffee-producing regions of Côte d'Ivoire, there is currently a conversion of old orchards for the establishment of new plantations [3]. The development of fallow land use for the establishment of new coffee orchards must be compatible with the nutritional needs of coffee trees. Moreover, a decline in soil fertility under coffee trees has been revealed in the major coffee-growing areas of Côte d'Ivoire [4]. This decline in soil fertility under coffee is partly linked to the lack of fertilizer input after more than fifty years of exporting soil minerals by coffee trees [5]. Soil quality is a key factor for good growing conditions, productivity and harvesting. The organic fraction of the soil improves structure, porosity, aeration and water availability in the soil, while the mineral fraction provides the nutrients necessary for good plant development [6]. The nutritional status of coffee plants can influence their ability to be resistant to biotic and abiotic stresses [7]. In addition, knowledge of the physical-chemical parameters of soils under coffee can help to identify potential production constraints and facilitate the interpretation of the nutritional status of coffee trees to allow recommendations on mineral feeding management [8]. This is the aim of the present work. To achieve this, the physical-chemical properties of soils under improved Robusta coffee varieties in the high production areas of Abengourou, Divo and Man have been determined. There were also identified the nutritional status of coffee trees and their growth abilities with regard to the level of fertility of these soils. Finally, the main constraints to the productivity of these soils have been identified, and recommendations for their improvement and sustainable use have been formulated.

2. MATERIALS AND METHODS

2.1 Study Areas

The research was conducted at three research stations sites of the National Center of Agriculture Research (CNRA) located in the coffee growing area of Côte d'Ivoire.

Abengourou site is located in the east of Côte d'Ivoire (6°43'47'' N, 3° 29' 47'' W). The relief of the region is made up of plains with an altitude of between 200 and 300 m. The annual temperature average is 26.3°C. The rainfall regime is bimodal with two rainy seasons: a short season between September and October and a long one between March and July. The annual rainfall average is 1171 mm [9]. Geologically, the soils of the station are derived from metamorphic rocks dating from the Precambrian period, and are for the most part of the ferralitic type, moderately leached on schists (Perraud et al., 1969). Divo site:

Divo site is located in the centre-west of Côte d'Ivoire (5° 48' N, 5° 18 W). The relief is made up of plains at an altitude of between 100 and 200 m. The climate is humid tropical with two rainy seasons: March to June and September to October, alternating with two dry seasons. The annual rainfall average is 1400 mm [9]. The annual temperature is between 28 and 32°C. The geological substratum of the Divo site dates from the Precambrian granitic period and consists of calc-alkaline granite, granodiorites and charnockites. The soils are ferralitic or ferralsol, moderately leached on granite [10].

Man site is located in the west of Côte d'Ivoire (7° 33'W, 7° 24'N). The relief is characterised by high plateaus at an altitude of between 500 and 700 m. Its climate is mountainous with two seasons, a rainy season lasting eight months from March to October, and a dry season from November to February. The annual temperature average is 25.2°C, with extremes of 23.5 and 26.9°C in December and March respectively. The average annual rainfall is over 1500 mm [9]. The geological substratum of the study site dates from the Precambrian period, composed of calc-alkaline granitic rocks, granodiorites and charnockites. The soils are ferralitic, developed on granitic rock with hypersthene [10].

2.2 Materials

The study was conducted for six months, between June and November. The edaphic material consisted of soil samples that were taken from under the fronds of the coffee trees. The plant material consisted of Robusta coffee trees. These are hybrids from clones in the process of being pre-popularised in the countryside. They were planted in the field after spending eight months in the nursery. These pre-extension varieties represent the new coffee varieties selected by the CNRA [1]. They are more productive than the popularised clones, and earlier entering production at one year after transplanting compared to two years for the clones.

2.3 Methods

2.3.1 Sampling

The subdivided plot design was used to collect the samples. At each site, the plot was subdivided into three blocks. Each block constituted a replication. Within each block soil and leaf samples were taken. The coffee trees on each plot were planted in a Fisher block design with 3 replications at a density of 1960 plants/ha (3 m x 1.7 m).

2.3.2 Agro - morphological measurements

The height of the stem and the length of the plagiotropic internodes were measured with a decameter from ground level to the last node bearing the apex. The measurement was made at the separation zone between the root system and the aerial part at 10 cm from the ground, using a caliper with an accuracy of 1/10 mm. Measurements were made on 50 trees per block. The number of orthotropic and plagiotropic internodes was counted. The measurements were carried out at 6-month intervals: the first measurement was made at the beginning of the trial and the second at the end.

2.3.3 Soil and leaf sampling

The soil samples were taken with an auger from the surface horizon (0-20 cm). The depth chosen corresponds to the horizons that are located at 90% of the absorbing roots as described by Hatert [11]. In each coffee plantation, and in each of the three blocks, 30 soil sampling points were taken and mixed to produce a single composite sample [12]. In other words, three homogenates per site and nine soil samples in total have been used. The soil samples were then sieved through a 2 mm mesh before being crushed and analysed. Leaf samples were taken between November and December, when the coffee trees were not bearing flowers or fruits. Nine leaf homogenates were obtained, three per site. The homogenates have been formed by four complete leaves (blade and petiole) of the third and fourth upper pairs of a plagiotropic shoot located halfway between the top and the collar [13]. These leaves were selected without dead zones, insect bites or apparent spots of fungi. The leaves of 50 coffee trees per block (i.e. 150 coffee trees) per site were sampled to constitute the homogenates. They were then oven-dried at 60^oC for 72 hours.

2.3.4 Measurement in the laboratory

The parameters measurements were done according to standard procedures [14]. Granulometry was determined by the international Robinson pipette method. Organic carbon (C) was determined by Walkley-Black method after oxidation with a mixture of sulphuric acid and potassium dichromate. Total nitrogen (N) has been established by the Kjeldahl method based on wet oxidation. Assimilable phosphorus (Pav) was determined by the Dabin method based on the use of a very dilute acid, 0.001N sulphuric acid. Cation exchange capacity (CEC) and exchangeable bases, such as potassium (K), calcium (Ca) and magnesium (Mg) were determined by the Metson method. K was determined using the flame photometer, while Ca and Mg were measured by atomic absorption flame spectrophotometry. The pH of the water was measured using a pH meter after adding 50 ml of ionised water to 20 g of soil followed by stirring and decanting.

2.4 Statistical Analysis

Analyses of variance (ANOVA) were performed using the statistical software R (version 2.0.2). Where tests were significant at the 5% level, means were compared using Tukey's test to identify those that were significantly different from others. Principal component analyses (PCA) were used to study the multivariate data obtained from the physicochemical measurements of the soils, the chemical measurements of the leaves and the agromorphological measurements of the coffee trees. This procedure makes it possible to group and distribute the variables and individuals with their sampling sites around the main axes, thus facilitating the observation of possible links between the variables and the places where they are most represented.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Physical-chemical characteristics of soils

The particle size analysis shows that sand is the most abundant particle size fraction in the surface layer of the three soils studied (Table 1). The clay content is higher in Man. Silt content is high in Abengourou. On the other hand, when considering the sand content, the Divo site has the highest value. According to the limits of the granulometric classes used in the ’Groupe d’Étude des Problèmes en Pédologie Appliquée’’ (GEPPA) system [15], the soils studied fall into the classes "silty-sandy-clay" for the Abengourou site, "sandy-clay" for Divo, and "clay-sand" for Man. The bulk density values are between 1.30 and 1.5. The pH of the three soils varies between 5.0 and 6.6. The Man soil, with a pH of 5, is strongly acidic compared to the Abengourou and Divo soils, which are moderately to weakly acidic, with values of 6.6 and 5.7 respectively. The soils studied have statistically different pH values. The average total carbon content of the soils is 2.01%, 1.18% and 1.95% for the Abengourou, Divo and Man soils respectively. The total nitrogen average content is quantitatively the same for Abengourou and Man (0.19%) and both different from Divo (0.13%). However, these differences are not statistically significant. Proportionally to the carbon content, the lowest organic matter content is recorded for the Divo soil (2.02%) compared to 3.46 % in Abengourou and 3.35 % in Man. The values obtained for the C/N ratio of the Abengourou (11.1), Divo (9.5) and Man (10.4) sites are not statistically different. The average total phosphorus (Ptot) contents, respectively (501.3 mg.kg^{-1}) at Abengourou, (378.3 mg.kg^{-1}) at Divo and (380.0 mg.kg^{-1}) at Man are not statistically different from each other. Available phosphorus (Pav), on the other hand, has higher values in Man (219.3 mg.kg^{-1}), followed by Abengourou (118.7 mg.kg^{-1}) and Divo (84.67 mg.kg^{-1}) and are all statistically different. The cation exchange capacities (CEC) of the three soils are statistically different from each other. The CEC of Abengourou and Man, respectively equal to 11.78 and 10.52 cmol.kg^{-1}, are higher than that of Divo (6.72 cmol.kg^{-1}). Statistical analysis shows in most cases different values for calcium, magnesium, potassium and sodium contents for the three soils. The soil at the Abengourou site has the highest sum of exchangeable bases. In general, the soils have a saturation level of less than 30 %. The ratios of K, Mg and Ca cmole.kg^{-1} cations (Ca/K, Mg/K and (Ca + Mg)/K) are also statistically different. The values obtained for the three sites show ratios that are all different from each other.

3.1.2 Agro-morphological parameters

The mean values of height increment was 24.33 cm at Abengourou, 38.32 cm at Divo and 13.81 cm at Man after 6 months of growth. Statistical analysis shows significant differences between the increase in height of the different sites (P= .001) after 6 months of observation (Fig. 1). The mean growth rates of the stem were 17.15, 12.20 and 6.44 mm after 6 months of observation. The statistical analysis shows significant differences between the three sites (*P= .001*). The mean values for the setting of orthotropic internodes were 6.17, 5.64 and 5.61, respectively for the Abengourou, Divo and Man sites after 6 months of growth. Statistical analysis shows significant differences between the different sites (*P= .001*) threshold over this period of the experiment. However, the number of orthotropic internodes was statistically homogeneous between Divo and Man. At the level of plagiotropic internodes, the average values were 4.24, 4.82 and 4.81, respectively for the Abengourou, Divo and Man sites after 6 months of growth. The statistical analysis shows significant differences between the different sites (*P= .001*). On the other hand, the number of plagiotropic internodes, statistically homogeneous between Divo and Man, was higher than that of Abengourou. Significant differences threshold over the experimental period for the growth in length of plagiotropic shoots were found between the three sites (*P= .001*). The values are 11.57, 16.69 and 12.59 cm, respectively in Abengourou, Divo and Man. The chemical element contents of the coffee leaves were determined at each site (Table 2). The results show significant differences between the nutritional statuses of the coffee trees at the different sites. Only for phosphorus Abengourou and Man had the same values. The leaves of the coffee trees content more nitrogen and phosphorus elements in Divo. In Abengourou, potassium, calcium and magnesium were the most abundant in coffee leaves.

3.1.3 Correlations between soil physicochemical properties, agro-morphological and chemical characteristics of coffee plants

The results of the principal component analysis (PCA) show two principal components selected on the basis of eigenvalue criteria greater than or equal to 1. The contribution of the components to the total variation in the first and second dimensions is 97.49%; 57.01% for axis 1 and 40.48% for axis 2 (Fig. 2). The first component is strongly correlated with the variables Kfol, Ca^{2+}, Mg/K, V, Mgfol, Ds, HT, (Ca.+Mg)/K, Nfol, and Cafol ($r > 0.73; P < .05$) on the positive side and strongly related to the variable Pav ($r < -0.97; P < .001$) on the negative side. The second component is strongly related to the variables CEC, K^+, OM, NON and Mg^{2+} on the positive side ($r > 0.77; P < .05$) and to the variables Pfol, NPN, LPN ($r < -0.81; P < .05$) on the negative side. These variables are also strongly correlated with each other on the different components. The factorial design of the individuals (Fig. 3) was used to establish the distribution of the soils of the experimental sites. These soils have broadly similar physicochemical profiles within the same site and different profiles outside the sites. The Man site is linked to the first component on the negative side. The second component is linked on the positive side to the Abengourou site while on the negative side is the Divo site. The soils of Man are relatively less rich in mineral elements except for Pav. The chemical status (Kfol, Mgfol and Nfol) of the leaves was low for coffee trees in Man. Growth (HT and Ds) and production (NON, NPN and LPN) parameters were relatively low in Man. The soils of the Divo and Abengourou sites have relatively better mineral profiles. The chemical status of coffee leaves was relatively higher than in Man. In terms of growth parameters, the Abengourou and Divo sites show the best performance. The difference between the Divo and Abengourou sites lies in the architecture. In Divo, the growth of coffee trees was more oriented towards width, whereas in Abengourou it was more oriented towards height. Referring to the data in Figs. 2 and 3, it can be seen that the main dimension of variability that contrasts the soils of the Man site with those of the Abengourou and Divo sites is their low capacity to support good growth of coffee trees.

3.2 Discussion

3.2.1 Agronomic suitability of soils according to physical -chemical characteristics

The physical-chemical characteristics of the soils were established in order to identify their agronomic potential. In the three study areas, coffee orchards are established on soils with high organic matter and mineral element contents such as nitrogen, potassium, calcium and magnesium. The organic characteristics were found to be deficient. These rates are considered low compared to the reference values [13,7]. The difference can be explained by the influence of the vegetation cover developed on these soils or possibly by the preceding fallow crop. In addition, the installation phase of the coffee trees returns little organic matter to the soil. Furthermore, the coffee trees are installed in full sun and not under shade. In addition, the soils of Abengourou and Man, which have relatively high organic matter contents, have high and optimal cation exchange capacities. This correlation between organic matter content and cation exchange capacity contributes to increasing the soil's cation exchange capacity, soil structure and water retention capacity [16]. This shows the importance of organic matter in soil fertility. Soil analyses revealed that total nitrogen levels did not differ between sites. However, the levels at all three sites were below the reference values [17,7]. On the other hand, at leaf level, nitrogen concentrations were statistically different between the three sites. These leaf concentrations were lower at Man. Similarly, leaf nitrogen concentrations were lower than the reference values [13]. As nitrogen is the most important element for coffee nutrition, it is found in insufficient quantities to meet the plants' needs. Moreover, in the absence of fertilization, the nitrogen available to the plant comes from mineralization by microorganisms. Although the soil contents are similar, their availability is affected by the lower pH of the Man soil. Indeed, nitrate (NO_3^-) being the assimilable form available to plants, it is activated in less acidic soils [18]. Thus, the uptake of nitrogen by coffee trees is reduced in acidic soil pH. The growth of coffee plants was differentiated between the different sites according to foliar nitrogen concentrations. Moreover, the correlation circle showed that height increments were significantly correlated with foliar nitrogen concentration. Although statistically different between the three sites, the available phosphorus content of the soils did not show substandard values [17,7]. In fact, these concentrations were very high in the soils of all three sites. However, not only did the foliar concentrations differ significantly from each other in their foliar phosphorus levels, but they were also below the reference values [13]. For some authors [19,20,21], phosphorus availability depends on the nature, state and content of the absorbing clay. The coffee plants at the three sites are growing on Ferralsol soils with a 1:1 mineral colloid load (generally kaolinites). Leaf concentrations were lower on soils with higher clay-silt content (Abengourou and Man). Furthermore, the low availability of available forms to crops is a result of fixation by iron and aluminium oxides and also of organic matter which increases their insolubility in the soil [22]. Low phosphorus levels tend to correspond with low increases in height, number and elongation of plagiotropic internodes which are parameters related to coffee productivity. Soil potassium levels in Divo and Man were below reference values [17,7]. Although the soil contents were statistically similar, leaf potassium concentrations were not deficient according to standards [13]. However, coffee trees in Man showed deficient values compared to the norms. Since K is a major essential element for coffee (Malavolta, 1986) and since its concentration is low in the leaves of coffee trees in Man, it becomes a limiting factor for the growth of coffee trees. Furthermore, a stronger correlation was found between leaf concentrations and radial growth of coffee trees. This result corroborates those of Malavolta [23] who found a strong correlation between the foliar status of coffee trees and dry matter synthesis. Soil calcium levels were statistically higher in Abengourou and Divo than in Man. However, calcium levels in all three soils were below the reference values [17,7]. Foliar calcium concentrations, although variable between sites, are in line with those established by Forestier [13], whereas soil analyses showed a potential deficiency at all three sites. Foliar calcium concentrations are lower at Man and are consistent with the low availability of calcium in the soil. Exchangeable calcium deficiencies are pronounced in acid soils [24]. This is the case for the sites in Man which had an acidic pH. The correlation circle shows that growth parameters were generally higher at sites with high leaf calcium concentrations (Abengourou and Divo). The magnesium contents of the soils of the three sites were statistically different but below the deficiency thresholds [17,7].. Only the sites of Divo and Man showed low levels according to the reference values [13]. In terms of foliar concentrations, coffee trees at the Man site showed the lowest levels and were clearly below the reference values. Mg levels were all well below the threshold for magnesium deficiency in tropical regions, which is 0.5 $cmol.Kg^{-1}$ [25] Furthermore, at the Abengourou and Divo sites where leaf concentrations were optimal, the coffee trees showed the highest growth rates. The highest sum of exchangeable bases (SBE) is 3.36 meq/100g for the Abengourou soil. These results are in agreement with those found by Boyer [26] who noted that the sum of exchangeable bases of moderately or highly desaturated ferrasols in tropical areas is between 2 and 6 meq/100g. This results in low saturation rates. Only a saturation rate (V) of 28.6%, i.e. at most 1/3 of the mineral elements are available on the Abengourou soil adsorbent complex, whereas saturation rates of soils under coffee trees should be around 60% [13,7]. Desaturation of the upper layers containing 80% of the root system is a factor in the physiological disorders of coffee trees. With regard to the chemical balance between the different exchangeable bases, the Mg/K and (Ca +Mg)/K ratios do not show any major imbalance between the elements Ca, Mg and K for the Abengourou and Divo sites. Moreover, these two sites show more or less similar levels [13]. The (Ca+Mg)/K ratio is low but acceptable at the Abengourou site and insufficient at the Man site. At Man, the K/Mg and (Ca+Mg)/K ratios are unbalanced and well below the reference limit. These different ratios were positively correlated to leaf concentrations and rates of increase of the different agronomic parameters of the coffee trees. Indeed, an exchange of the nutrients K, Mg and Ca occurs during the assimilation by the plants. Higher or lower concentrations of one element, outside the reference limits, hinder the assimilation of the other. These observations are in agreement with those of Forestier [13], Snoeck [27] and Carvajal [28] on the mineral nutrition of coffee plants. Indeed, these authors argue that good development of the coffee tree is dependent on the balance and availability of bases in the soil. Highly significant correlations obtained between soil physicochemical parameters, different ratios, leaf chemical parameters and agro-morphological parameters confirm the importance of soil mineral availability and chemical balances in coffee tree nutrition.

3.2.2 Growth and nutritional status of coffee trees

In this study, increases were more significant at Abengourou and Divo than at Man. This is generally explained by the availability of mineral elements which are relatively more important in the soils of the Abengourou and Divo sites than in Man. The rate of increase can also be explained by the climatic conditions at the different sites. In Man the average temperatures are lower than in Divo and Abengourou. Similar studies on the growth and development of coffee trees have noted the regressive effect of temperature on the morphological parameters of coffee trees [29]. The analysis of the data reveals that the chemical compounds measured in the leaves show significant differences between the nutritional statuses of the coffee plants at the different sites. Two phenomena can explain this difference. Firstly, it can be explained by the physicochemical characteristics of the soils that were different from one region to another. Furthermore, according to Forestier [13], the mineral supply of the coffee plant is closely linked to the characteristics of the soil, which generally provide the plants with the minerals they need. However, the physicochemical characteristics are not the only ones responsible for the mineral supply of coffee plants. Climatic conditions play a major role, especially local rainfall. In the case of coffee, regular rainfall is a determining factor in plant development. However, on the Abengourou and Divo sites, where the nutrient status seems to be better than that of Divo, rainfall is regular compared to the Man site, which is characterised by more abundant, but monomodal rainfall [9]. Consequently, after the monomodal rainfall phase, a long dry phase follows, slowing down the growth of the coffee trees.

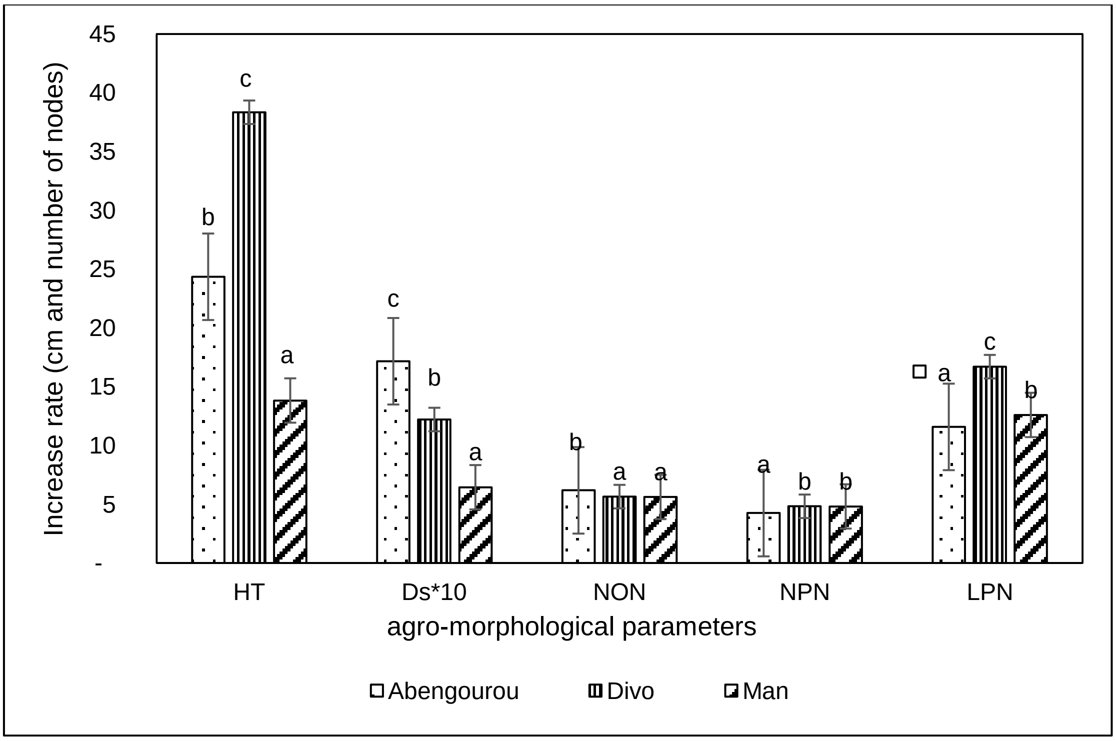

Fig. 1. Increase in agro-morphological parameters

HT: Height increment, Ds: Diameter of stem, NON: Number of orthotropic internodes, NPN: Plagiotropic internodes and PNL: Plagiotropic internode length. Columns are mean values ± SD. N=3. Columns marked marked with the same letters are not significantly different according to the Tukey test at the 5% threshold

Table 1. Physical-chemical properties of soil (0-20 cm)

Features	Abengourou	Divo	Man
Clay + silt (%)	52.80 ± 4.51 a	35.7 ± 4.07 b	47.8 ± 0.61 a
Clay (%)	13.80 ± 1.18 c	17.54 ± 2 b	31.37 ± 0.40 a
Silt (%)	39.00 ± 3.33 a	18.1 ± 2.06 b	16.4 ± 0.21 b
Sand (%)	42.40 ± 3.62 b	61.8 ± 7.03 a	48.5 ± 0.62 b
pH	6.60 ± 0.06 a	5.7 ± 0.06 b	5.0 ± 0.06 c
Total carbone(C), (%DM)	2.01 ± 0.11 a	1.18 ± 0.1 b	1.95 ± 0.26 a
Total nitrogen (N), (%DM)	0.19 ± 0.05 a	0.13 ± 0.03 a	0.19 ± 0.02 a
C/N	11,1 ± 2.27 a	9.5 ± 1.14 a	10.4 ± 0.56 a
Organic matter (OM), (% DM)	3.46 ± 0.18 a	2.02 ± 0.17 b	3.35 ± 0.44 a
Total phosphorus(P), ($mg.kg^{-1}$)	501.3 ± 20.6 a	378.3 ± 124.2 a	380.0 ± 93 a
Available phosphorus ($mg.kg^{-1}$)	118.7 ± 13.5 b	84.67 ± 9.3 c	219.3 ± 13.6 a
CEC [$cmol(+).kg^{-1}$]	11.78 ± 0.24 a	6.72 ± 0.16 c	10.52 ± 0.12 b
Exchangeable Ca ($cmol.kg^{-1}$)	0.93 ± 0.08 a	0.87 ± 0.02 a	0.18 ± 0.02 b
Exchangeable Mg ($cmol.kg^{-1}$)	2.00 ± 0.24 a	0.65 ± 0.03 b	0.13 ± 0.02 c
Exchangeable K ($cmol.kg^{-1}$)	0.39 ± 0.01 a	0.11 ± 0.01 b	0.10 ± 0.00 b
SEB ($cmol.kg^{-1}$)	3.4 ± 0.33	1.7 ± 0.02	0.4 ± 0.03
V (%)	28.6 ± 3.40 a	24.6 ± 0.92 a	3.9 ± 0.32 b
Mg/K	5.2 ± 0.50 a	6 ± 0.37 a	1.3 ± 0.21 b
Ca/K	2.4 ± 0.16 b	8.1 ± 1.08 a	1.9 ± 0.19 b
(Ca +Mg)/K	7.6 ± 0.66 b	14.1 ± 1.46 a	3.2 ± 0.36 c

±: standard deviation for three replicates, C/N: carbon/nitrogen ratio, SEB: sum of exchangeable bases, V: saturation rate. Within a row, numbers marked with the same letters are not significantly different according to the Tukey test at the 5% threshold

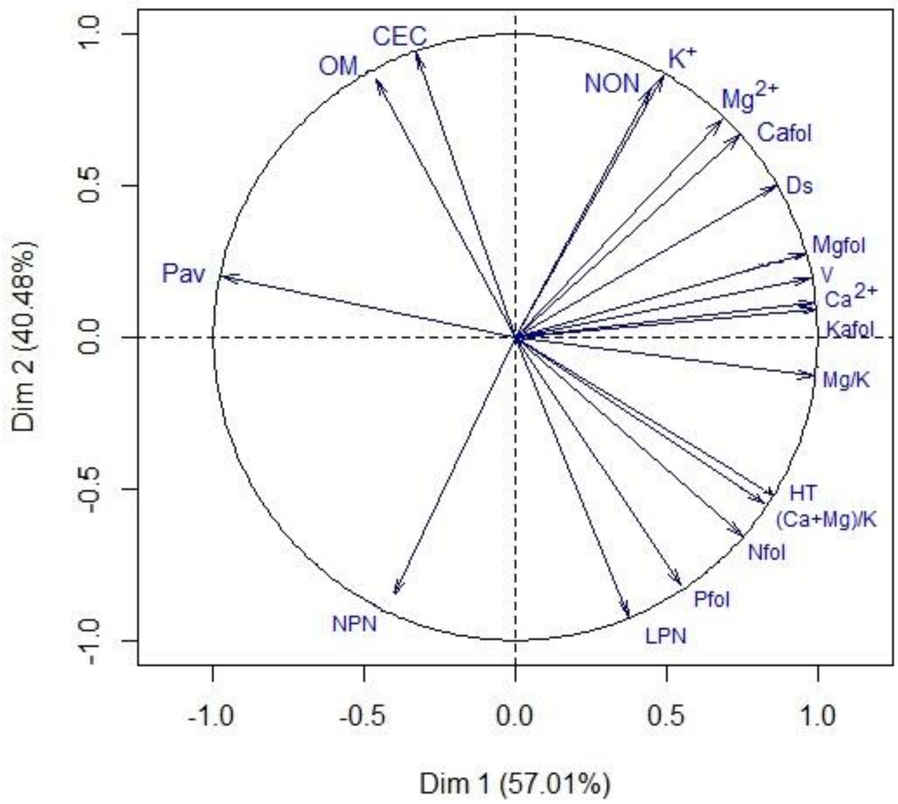

Fig. 2. Correlation circle (axis 1 and 2) for the different groups of variables
OM: Organic Matter, Pav: Available phosphorus, Nfol: Foliar nitrogen, Kfol: Foliar potassium, Pfol: Foliar phosphorus, Cafol: Foliar calcium and Mgfol: Foliar magnesium

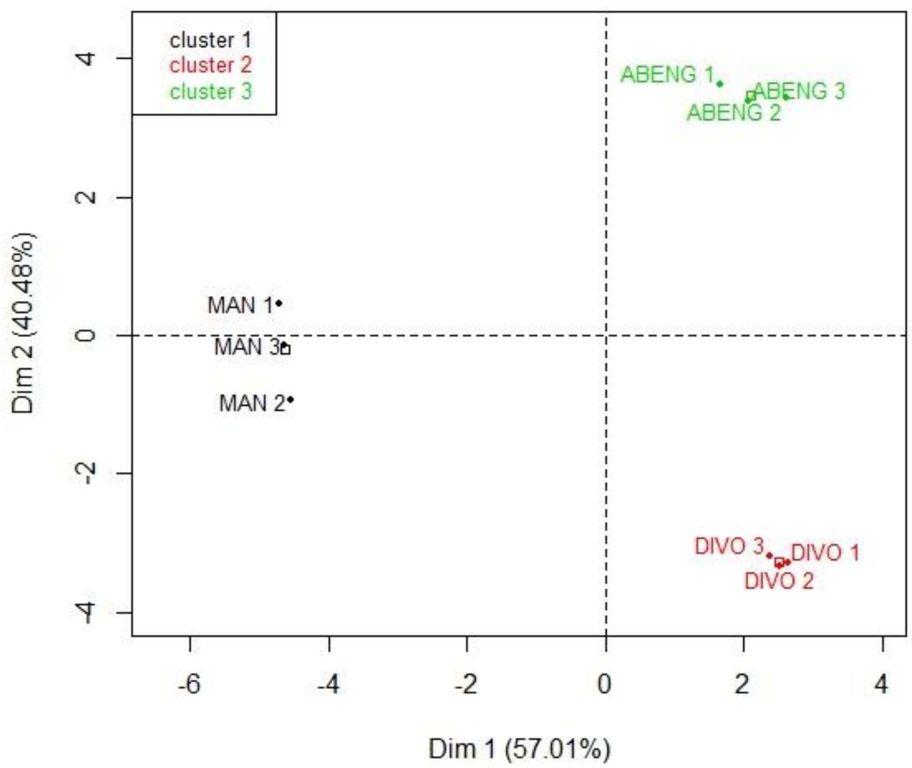

Fig. 3. Clustering of individuals in the factorial plane formed by the F1 and F2 axes
ABENG: Abengourou

Table 2. Nutrient status of macronutrients in coffee trees

Features	Abengourou	Divo	Man	Reference [13]
Nitrogen (% DM)	0.360 ± 0.02 b	0.643 ± 0.012 a	0.250 ± 0.01 c	2.5 – 3.0
Phosphorus (% DM)	0.070 ± 0.001 b	0.119 ± 0.008 a	0.070 ± 0.002 b	0.15 – 0.2
Potassium (% DM)	2.176 ± 0.002 a	2.146 ± 0.007 b	1.481 ± 0.01 c	1.5 – 2.6
Calcium (% DM)	1.749 ± 0.004 a	1.166 ± 0.012 b	0.841 ± 0.01 c	0.7 – 1.3
Magnesium (% DM)	0.298 ± 0.002 a	0.263 ± 0.002 b	0.151 ± 0.002 c	0.2 – 0.4

±: Standard deviation for three replicates, DM: Dry Matter. Within a row, numbers marked with the same letters are not significantly different according to the Tukey test at the 5% threshold

4. CONCLUSION

Coffee is a plant that adapts to different types of soils, provided that the levels of different minerals are adequate to support its growth and development. The results obtained show that the soils of the Abengourou, Divo and Man sites are very distinct from each other, although they are all suitable for coffee growing. The growth and development of the coffee trees was well differentiated in Abengourou and Divo where the physicochemical characteristics of the soils and the nutritional status of the coffee trees were higher than in Man. Analyses of the nutritional status of the coffee trees showed the influence of leaf concentration levels on growth parameters. In addition, a relatively triple positive correlation was found between the physicochemical characteristics of the soils, the chemical status of the coffee trees and their growth and development abilities. The leaf analysis gives an accurate picture of the nutritional status of the coffee tree, but does not give any indication of the causes of deviations from the norm. For a better management of soil fertility, organic and chemical characteristics (soil mineral contents and chemical balance between these elements) should also be considered with regard to the needs of the coffee tree.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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