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Soil fertility of cocoa trees (*Theobroma cacao* L.) under cassava (*Manihot esculenta* Crantz) shade in south-central Côte d'Ivoire.

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ABSTRACT

Objective: To protect young cocoa trees in climate change context marked by drought and lack of arable land, and diversify shade trees for cocoa, cassava was proposed as shade. To enhance this association, a study was carried out to determine the influence of shade types on soil fertility under cocoa trees.

Methodology and results: A physico-chemical analysis of soil samples from cocoa trees shaded by one line, two lines of cassava and one line of banana trees was carried out. In physical terms, results showed that soil texture is silty-clayey-sandy, whatever the type of shading. Organic matter levels were low in soils under cassava shade compared with banana shade. In chemical terms, phosphorus, potassium, soil organic carbon, the sum of exchangeable bases, magnesium and the saturation rate decreased in the various shades compared to plot without cocoa trees. Cation Exchange Capacity and the C/N ratio, despite decreasing in different types of shade, remain within cocoa-growing standards.

Conclusions and application of results: Finally, the study showed that cassava can be used as temporary shade for young cocoa plants in the same way as banana, which the shade recommended by the research. However, the cassava variety chosen must be considered and planted in the cocoa tree rows at a distance of 1.5 metres. This diversification of temporary shade for cocoa provides more choice to cocoa producers since cassava is quite available and hardier than banana.

Key words: banana, cassava, cocoa, fertility, shade.

INTRODUCTION

Cocoa tree (*Theobroma cacao L.*) is a tropical plant in the Malvaceae family that was introduced to eastern Côte d'Ivoire at the end of the 19th century (Bastide, 2007; Kouakou *et al.,* 2013). After a difficult start, cocoa farming has expanded very rapidly thanks to the availability of fertile land in the forest zone and an influx of labour from inside and outside Côte d'Ivoire (UN-REDD, 2016; Koua *et al.,* 2018). Today, the cocoa industry is a key economic and social sector for the country (Coulibaly, 2014; UN-REDD, 2016). Today, the cocoa industry is a key economic and social sector for the country (Coulibaly, 2014; UN-REDD, 2016). The sector contributes 15% of the country's Gross Domestic Product (GDP) and 50% of its export earnings (BAD, 2020). With 2.1 million tonnes of merchantable cocoa for the 2019-2020 season (ICCO, 2020), Côte d'Ivoire remains the world's leading cocoa-producing country (ICCO, 2020). Compared with other perennial crops, cocoa generally needs shade. It is therefore traditionally planted under mixed forest shade trees. Forest trees are used for permanent shade and plantain is generally planted for temporary shade when new plantations are established (Frimpong *et al.,* 2000). In Côte d'Ivoire, the system of growing cocoa in full sun under a shade of banana trees on the basis of one banana tree for one cocoa tree was recommended and adopted by producers (Lachenaud, 1987). However, the high inter-annual climatic variability observed in recent years, characterised by prolonged droughts and decreasing rainfall, has rendered certain areas that were previously favourable for cocoa cultivation increasingly marginal (Assi, 2021). This has led to high mortality among cocoa plants. In addition, it is increasingly clear that banana is becoming drought-sensitive in certain production areas and is beginning to be unsuitable for temporary shade (Frimpong *et al.,* 2000). Under such conditions, it appeared necessary to propose other crops as temporary shade trees for the cocoa tree. In this perspective, cassava, which is a popular food crop and widely grown in the orchard, was proposed as a temporary shade for the cocoa tree. Cassava is a hardy plant from the humid tropics with a great capacity to adapt to both climate and soil (Egle, 1992). The aim of this study was to determine the influence of different types of shade consisting of banana and manioc on soil fertility under cocoa trees.

MATERIALS AND METHOD

Study site: The study was carried out at the National Centre for Agronomic Research (CNRA) research station in Divo, 200 km from Abidjan (the economic capital of Côte d'Ivoire) and 17 km from the town of Divo, in the forested area in the south of the country.

Plant material: The plant material used consists of cocoa plants from a mixture of several cocoa varieties, then upright cassava plants and banana plants used for shade.

Method

Experimental set-up: The trial was conducted using a Fischer block design with the type of shade as the treatment, i.e. 3 treatments. Each treatment, repeated three times, was represented by 5 lines of 10 useful cocoa trees and 2 border plants. The blocks were separated from each other by 5 m and each block was surrounded by a border consisting of a line and a row of cocoa trees. The total area of the trial was 0.33 ha.

Soil sampling and analysis: The morphological characterisation of the soil in the experimental plot consisted in determining its texture. Soil samples were taken from the plot with 3-year-old cocoa trees under banana and cassava shade. To carry out this activity, a cylindrical tube 1.20 m long, perforated every 20 cm and 5 cm in diameter, was used. It was driven vertically into the ground to a depth of just 20 cm by striking the steel plate welded to the upper end of the tube with a 5 kg hammer. Soil samples were therefore taken only from the 0-20 cm horizon. Soil samples were taken from three randomly selected cocoa trees on each of the five (5) lines making up a treatment or elementary plot. For each treatment or elementary plot, fifteen (15) soil cores were taken per block, i.e. 45 soil samples for each treatment over the entire plot. The 45 samples obtained per treatment were pooled and homogenised to form one composite sample per treatment, i.e. 3 composite samples for the trial. The composite samples were air-dried for 72 hours in a hangar. After drying, the samples were sieved using a 2 mm square mesh sieve. A 150 g portion of each composite sample per treatment was then used for the various analyses at the Office Chérifien des Phosphates (OCP) laboratory. The other part of the samples was kept in plastic bags for possible verification. Samples taken from different parts of the plot before the crops were planted were pooled to form the control.

Soil texture: Texture was assessed in situ using the tactile or pudding method. For the 20 cm horizon, the fine soil was sampled and soaked in water. This sample of soil was kneaded between the fingers to form a pudding. Soil texture is determined according to the following results:

(i) whether or not a sulcus is formed,

(ii) if a sulcus is formed, it breaks into 1, 2, 3 or forms a ring (Yoro, 2004). In addition to this in situ morphological characterisation, the texture of these samples was also determined in the laboratory by granulometric analysis using the Robinson (1922) method described by Baize and Jobiol (1995). The clay content of the different textural classes was estimated based on the triangle of fundamental soil texture classes developed by Duchaufour (1997).

Physico-chemical analysis of soil samples: For the chemical analysis of the soil, three replicate soil samples were taken from each of the three composite samples for chemical analysis. The soil was analysed for organic matter (OM), C, N, K, Mg, Zn and Cu content, water pH, Sum of Exchangeable Bases (SBE) and Cation Exchange Capacity (CEC). From these assays, several ratios and rates were calculated. These were:

- SBE+6.15/N ratio, which determines nitrogen and exchangeable base requirements;
- Mg/K ratio, which determines magnesium and potassium requirements;
- C/N ratio, used to assess the degree of degradation of organic matter;
- saturation rate, which represents the filling rate of the soil reservoir.

Statistical analysis: A one-factor analysis of variance (Anova) was performed using SAS 9.4 software. A comparison of means using the Newman-Keuls method was applied at the 5% probability threshold.

RESULTS

Physical characterisation of the soil under different types of shade: The results of the physical analysis of the soil samples (Table 1) showed that the cocoa tree soils under the different shades (banana, one (1) row and two (2) rows of cassava) and the soil without crops have a sandy-clay texture with 15 to 25% clay.

Table 1: Soil texture as a function of different shading conditions

Types of plot	**Soil constituents**			
	Clay (%)	**Silt (%)**	**Sand (%)**	**Organic matter (%)**
Control (without cocoa trees)	24.90±0.15 a	38.80±0.80 c	36.4±0.60 b	5.22±0.0001 a
Cocoa trees shaded by a line of banana trees	22.70±0.56 b	40.10±0.66 c	37.2±0.95 a	2.958±0.0001 b
Cocoa trees shaded by one line of cassava	19.90±0.62 c	46.1±0.49 a	33.9±0.58 b	2.088±0.00001 c
Cocoa trees shaded by two lines of cassava	20.80±0.23 c	43.0±1.00 b	36.3±0.65 b	1.91±0.0005 d
Mean	22.07	42	35.95	3.05
Cv (%)	34.8	31.4	34.3	25.21
P	0.0002	0.0006	0.521	<.0001
Standards				3%

Means with the same letter in the same column are not significantly different at the 5% threshold.

Chemical characterisation of cocoa tree soil under different shades: The results of the analysis of the chemical characterisation of the soil of cocoa trees under different shades (Table 2) showed a significant difference between treatments. Differences were observed in the pH of the water, but the soils in the various treatments were acidic, with pH values ranging from 5 to 6.1. In terms of soil organic carbon, the control plot, on which no cocoa trees were planted, had the highest level of carbon (3.0%), while the lowest levels were observed in the soil of cocoa trees under cassava shade, with a level of 1.1%, regardless of the number of cassava rows. Soil from cocoa trees shaded by a line of banana trees stored 1.7% organic carbon. Regarding nitrogen, the soil without cocoa trees stored a greater quantity of nitrogen (0.29%) than that present under cocoa trees, and the values recorded in table 2 (0.12, 0.13 and 0.16%) do not show any statistically significant difference. The C/N ratio was high and statistically similar in the soils of the control plots (13.30) and cocoa trees shaded by two (2) lines of cassava (12.9). Similarly, the lowest values observed for the soils of cocoa trees under banana shade (10.70) and one (1) line of cassava (10) showed no statistical difference. Regarding assimilable P, the cocoa tree soil planted under banana shade had the highest content (10 cmol (+).kg-1) compared with the other treatments, which recorded statistically identical low levels (6 to 7 cmol (+).kg-1). At the level of the adsorbent complex, analysis of variance showed significant differences between the different treatments. The highest value of cation exchange capacity (CEC) was obtained in the soil of the control (18 cmol (+).kg-1) and, in decreasing order, in the soil of cocoa trees shaded by two (2) lines of cassava (30 cmol (+).kg-1), banana (20 cmol (+).kg-1) and one (1) line of cassava (10 cmol (+).kg-1). With regard to the sum of exchangeable bases (SBE), the highest content was observed in the soil of the control (11.14 cmol (+).kg-1), while the lowest content was obtained in the soil of cocoa trees shaded by two (2) lines of cassava (3.6 cmol (+).kg-1). With regard to the (SBE+6.15)/N ratio, the control soil had the highest content. The lowest levels were observed in the soils of cocoa trees shaded by one (1) line of cassava, followed by cocoa trees shaded by banana trees, with levels of 48.70 and 49.83 respectively. An average value is obtained for the soil of cocoa trees shaded by two (2) lines of cassava. As for the saturation rate (V), the control had the highest rate (63%) and the lowest (32%) was observed with the cocoa tree soil shaded by two lines of cassava. However, the saturation values of the soils of the cocoa trees shaded by banana and one line of cassava remained low (< 50%). And like calcium, the magnesium content was slightly higher in the control soil (2.1 cmol (+) kg-1) and lower in the soil from cocoa trees shaded by one (1) line of cassava. Average levels were obtained in the soil of cocoa trees shaded by two (2) lines of cassava and banana. In terms of potassium content, no significant difference was observed between treatments. The highest value of the Mg/K ratio was recorded in the soil of cocoa trees shaded by one (1) line of cassava (14), while the lowest value was obtained in the soil of cocoa trees shaded by banana (5). For microelements, there are significant differences in copper and zinc. The highest copper content was observed in the soil of cocoa trees shaded by one (1) line of cassava (1.60 cmol (+) Kg-1), while the lowest levels were obtained in the soil of the control (0.90 cmol (+) Kg-1) and the other treatments (cocoa trees shaded by banana (0.60 cmol (+) Kg-1) and two (2) lines of cassava (0.80 cmol (+) Kg-1). Concerning zinc, the highest level was observed in the soil of cocoa trees shaded by one (1) line of cassava (26.00 mg/kg). In decreasing order, it was followed by that in the soil of cocoa trees shaded by two (2) lines of cassava, banana trees (18.40 mg/kg) and the control (10.00 mg).

Table 2. Soil chemical characteristics of cocoa trees under different types of shade

Chemical characteristics		**Types of shade**					
pH and microelements	Control	Cocoa trees shaded by one line of cassava	Cocoa trees shaded by two lines of cassava	Cocoa trees shaded by a banana line (Relative control)	Cv (%)	Pr	Standards
pH eau	6.10±0.05 a	5.1±0.10 c	5.0±0.05 c	5.4±0.10 b	26.18	<.0001	6.7-7.5
COS (%)	3.0±0.05 a	1.1±0.11 c	1.1±0.05 c	1.7±0.11 b	9.03	<.0001	_
N (%)	0.29±0.005a	0.13±0.01 b	0.12±0.01 b	0.16±0.03 b	20.60	0.0014	1 kg. g^{-1}
C/N	13.30±0.2 a	10.70±0.28 b	12.9±0.85 a	10.00±0.15 b	11.69	0.0027	entre 9 et 15
P ass (%)	7.00±0.36 b	7.00±0.15 b	6.00±0.28 b	10.00±0.56 a	12.8	0.0004	100 ppm ou 60%
Adsorbent complex							
CEC	18±0.57 a	10±1.00 d	30±1.73 b	20±0.55 c	46.28	<.0001	12<CEC<30
SBE	11.74±0.12 a	5.30±0.10 b	3.6±0.05 c	5.2±0.05 b	8.7	<.0001	-
(SBE+ 6,15)/N	60.51±0.20 a	48.70±0.45 c	52.4±0.64 b	49.83±0.63 c	22.1	<.0001	-
V(%)	63±0,002 a	39±0.005 c	32±0.006 d	49±0.005 b	9.31	<.0001	-
Ca (cmol (+) kg^{-1})	7.20±0.05 a	2.70±0.10 c	3.60±0.15 b	2.40±0.11 c	39	<.0001	68 % ou ≥5.8
Mg(cmol (+) kg^{-1})	2.1±0.11 a	0.8±0.05 c	1.40±0.11 b	1.5±0.04 b	37.85	<.0001	24 % ou≥0.8
K (cmol (+) kg^{-1})	0.30±0.01 a	0.10±0.01 a	0.10±0.015 a	0.30±0.01 a	2.97	0.0749	8 % ou≥1.2
Mg/K	7±0.10 c	14±0.10 a	8±0.10 b	5±0.05 d		<.0001	
Trace elements							
Cu (ppm)	0.90±0.005 b	1.60±0.20 a	0.80±0.05 b	0.90±0.005 b	18.8	0.0008	-
Zn (mg/Kg)	10.00±0.28 d	26.00±1.36 a	21.40±0.30 b	18.40±0.61 c	7.09	<.0001	-

Means followed by the same letter on the same line are statically identical (Newman-Keuls test, P = 5%)

DISCUSSION

The cocoa tree is originally found in the lower layer of the Amazon rainforest and does not tolerate direct sunlight (Brucher, 1977, Deheuvels, 2011). Shading is therefore absolutely necessary for newly established young cocoa trees in order to reduce water loss during the dry season. Temporary shade can be provided by food crops such as banana and cassava, which could provide income to the farmer until the cocoa trees mature and start producing (Anonymous, 2013). Shading is therefore absolutely necessary for newly established young cocoa trees in order to reduce water loss during the dry season. Temporary shade can be provided by food crops such as banana and cassava, which could provide income to the farmer until the cocoa trees mature and start producing (Anonymous, 2013). However, as cassava is considered to be a soil-depleting crop in terms of the mineral mobilisations it causes (Pouzet, 1988; Shackelford *et al.,* 2018), it would be important to test its suitability from a pedological and agronomic point of view before recommending it as a temporary shade for cocoa. The physico-chemical analysis of cocoa tree soils grown for three years under banana and cassava shade (1 and 2 rows) was used to determine their level of fertility. From a physical point of view, the texture of the soil was unchanged regardless of the type of shading used. All the soil samples analysed contained sand, clay and silt like the control, i.e. the plot without cocoa trees. These results show that shading with cassava did not damage the soil texture 3 years after cultivation. The soil texture remained the same compared with the soil without cocoa trees and under banana shade taken as a reference. However, the results obtained by Cong Doan Sat & Huang Van Tam (1999) showed that long-term cassava cultivation leads to physical degradation of the soil on which it is grown, particularly a drop in clay content. Generally speaking, the pH of the soils in the control plot (without cultivation) and under the different types of shade is acidic, with pH values of between 5 and 6. However, the acidity increased in the cocoa soils under cassava shade. These results are in line with those obtained by Sedogo (1993) and Hien (2004), who noted that cassava cultivation leads to a drop in pH value if no fertiliser is applied. The general drop in organic carbon levels in cultivated soils could be explained by the degradation of organic matter. Once the plant cover has been destroyed by burning, it is replaced by the leaves and other organs of cultivated plants. If the crops produce a large amount of organic matter, more of it will be sequestered in the soil. The sharp decline in organic carbon in cocoa soils under cassava shade could therefore be explained by the fact that cassava produces a small amount of organic matter. Similar results have been found by several researchers (Contepas & Makilo, 1982; Cong Doan Sat & Deturck 1998), who observed that under cassava cultivation, the organic stock in the soil declines rapidly from the first few years. The C/N ratios obtained (10 to 12.90) in this study indicate a balance between the processes of mineralisation and humification of organic matter in cocoa tree soils under different shades. Indeed, according to the limit values (9-15) for the 'normal' supply of nitrogen to plants established by Tossah et al. (2006), cocoa trees under these different types of shade receive good nitrogen nutrition. This is shown by the nitrogen content, which did not vary in the soils of cocoa trees under banana and cassava shade. On the other hand, the reduction in the quantity of phosphorus in the soils of cocoa trees under cassava shade, compared with that found under banana shade, could be explained by the fact that cassava requires a high concentration of this mineral for its development, in particular the formation of tubers (Peña Venegas *et al.,* 2021). Tuberisation requires the storage of starch, the synthesis of which is highly dependent on ATP, which comes from the phosphorylation of ADP. Most of this phosphorus comes from the soil solution. This hypothesis is all the more plausible as the lowest value of this mineral was obtained in the soil of cocoa trees shaded by two (2) lines of cassava. Work carried out by Sylvestre (1987) and IITA (1990) gave similar results. Cation exchange capacity (CEC), which measures a soil's capacity to retain mineral elements, is an indicator of its fertility. The CEC obtained in cocoa tree soils under the various shades (10 to 30 cmol.kg-1) showed that these soils have a good mineral element retention capacity. Indeed, according to Snoeck *et al.* (2015), cation exchange capacity is normal when it is between 12 and 30 cmol.kg-1. However, the low levels (3.6-5.3) of the sum of exchangeable bases (SBE) in all shade types, below the threshold defined (8.9) by N'guessan et al. (2015) could hamper crop productivity. According to these authors, an SBE of less than 8.9 is an indicator of the soil's lack of exchangeable bases. For Jadin & Snoeck (1985), the low SBE value reflects a sufficient level of nitrogen. . These low SBE levels were confirmed by the low exchangeable base saturation rates (below 60%) under all the different types of shade. Exchangeable base saturation rates represent the filling rate of the soil reservoir. Similar results were obtained by Smith (1980) who mentioned that soils under cocoa trees were moderately or highly desaturated on the surface. In cocoa trees under manioc shade, the drop in saturation could be explained by the acidity caused by manioc cultivation. Magnesium levels were lower in the soils cultivated under shade than in the uncultivated soils but remained within the norms for cocoa cultivation. The drop in potassium levels in cocoa soils under cassava shade could be due to the continuous cultivation of cassava on the same plot. These results agree with those of Vernier *et al, et al,* (2018) who stated that cassava grown continuously without external fertiliser on the same plot depletes it by first decreasing potassium, then nitrogen, magnesium and calcium. The Mg/K ratios of the soils from the different treatments were generally greater than 3. In fact, these values obtained during this study are within the ranges proposed by certain authors (Boyer, 1982; Jadin & Snoeck, 1985) who have mentioned that a Mg/K ratio greater than or equal to 3 would be favourable to most tropical crops, including cocoa. Despite these fluctuations, the soils of cocoa trees under cassava shade were not very different from those of cocoa trees under banana shade taken as a reference.

CONCLUSION AND APPLICATION OF RESULTS

In Côte d'Ivoire, cocoa farming is often combined with food crops which, by providing temporary shade for young cocoa trees, also provide food and/or income for farmers. This study was carried out to determine the behaviour of young cocoa trees under cassava shade compared with those under banana shade. Concerning the influence of shading types on the fertility of cocoa tree soils, the physico-chemical analysis of the soils from the different treatments showed that soil texture had not been modified. It is silty-clayey-sandy whatever the type of shade, i.e. the plant associated with the cocoa trees. On the other hand, pH and organic matter decreased, especially in cocoa soils under cassava shade. The C/N ratio remained within the norms for cocoa cultivation. Nitrogen content was statistically identical for all soil types. A drop in phosphorus content was observed in the soils of cocoa trees shaded by cassava, with a lower value in the soil of cocoa trees shaded by two (2) lines of cassava. The cation exchange capacity (CEC) of the soils under the different shades was approximately good (10-12 cmol.kg-1). However, the exchangeable base saturation rates of the soils under the different types of shade were all below the standard for cocoa, set at 60%. Magnesium levels were lower in soils cultivated under shade than in uncultivated soils. However, they remained within the norms for cocoa cultivation, i.e. 0.8 cmol.kg-1. As for potassium, the levels obtained in all the soil samples were very low (0.1-0.3 cmol.kg-1) compared with the standard for cocoa farming, which is set at 1.2 cmol.kg-1. The soils of the different types of shade (cassava and banana) obtained an Mg/K ratio, generally higher than 3, which would be favourable to cocoa cultivation.

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