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Savannah Soils Fertility Diagnosis for Optimal Cotton (Gossypium Hirsutum L.) Management in Northern Côte d'Ivoire

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Abstract **Original Research Article**

In savannah environments, soil constituents nature and structuration undergo significant and rapid transformation which could impair their use. Some of these transformations are due to changes in human activity, resulting from unsuitable cultivation practices, and overexploitation of the land, which is accompanied by a decline in cultivated soils fertility. A baseline survey was conducted to diagnose cotton-grown soils in terms of fertility and long-term sustainable utilization. Six locations were selected in the vast cotton cultivation zone in northern Côte d'Ivoire. Soil pH varied from slightly acidity to neutral, suggesting good acidity level for optimum cotton growth. However, there were deficiencies in nutrients, which differed from one soil to another: soil organic carbon was lower than 5 %, total N was very low in Boundiali and Korhogo, and soil assimilable phosphorous was very low in Boron, Diawala and Ferkessédougou. Soil grouping using a principal component analysis showed some similarities among the studied cotton-grown soils and constitutes a clue to align soils fertilization strategies. The analysis of soil amendments should focus on macronutrient and specific secondary nutrients like Ca, S, and Mn input. Furthermore, cotton-grown soils fertilization should be done through organic amendment.

Keywords: Fertility, Cotton-Grown Soil, Savannah, Côte d'Ivoire, Soil Nutrients.

INTRODUCTION

Cotton is a cash crop that contributes to the socio-economic development of households in cotton-growing regions. It strengthens the diversification of agricultural exploitation, reduces the level of monetary poverty in villages, improves rural housing, facilitates peasant mobility, creates new jobs, improves literacy and health levels (Aiwa, 2015; Tillie *et al.*, 2018). In Côte d'Ivoire, it represents between 5 and 10% of Côte d'Ivoire's exports and generates an annual turnover of around 120 billion FCFA (Berti *et al.*, 2006). Its production contributes to GDP growth is timated to 1.7% and its export share has reached 7% (Koffi, 2013).

In the north of the country, cotton has established itself as the reference cash crop in the regions(Tillie *et al.*, 2018). Despite significant inputs of fertilizers, the average yield of the cotton sector remains below 1,100 kg ha^{-1} (FAO, 2020). Drawing lessons from the weaknesses of the cotton sector, the government has replaced, from the 2014/2015, the fertilizer subsidy by a direct support at the price paid to producers per kilogram of seed cotton. In the same period, seed cotton production reached its highest historical level of 50,000 tons, which marked a new inflection in the attractiveness of cotton production for Ivorian farmers.

However, extensive cotton cultivation contributes to arable land reduction. There is strong land pressure marked by the gradual and regular decrease, with an estimated loss of nearly 90,000 hectares of cotton-cultivated area sown, during four years of production. This could be due to agricultural mismanagement practices. These practices promote compaction (Coulouma *et al.*, 2006), erosion (Le Bissonnais *et al.*, 2007) and the reduction of chemical indicators values (Diomandé *et al.*, 2021).

These practices, with unfavourable effect on the soil, induce the decrease in cultivated area per cotton farmer and gradual drop in cotton yield. Consequently, from 2015 to 2018, the average production of seed cotton, grown on an average area of 357,061 ha, produced 350,280,513 tons, yielding 981 kg ha^{-1} (COIC, 2021; FIRCA, 2018). The drop in yield is attributable to several factors of which one of the mains is the level of nutrients essential for the cultivation of cotton (Diomandé *et al.*, 2021). In this context, this work was conducted to discriminate cotton-grown soils, based on their physico-chemical indicators, potentially modified by cultivation practices. The objective of this work was to investigate the spatial distribution of these indicators in six cotton growing locations of the "cotton basin" of Côte d'Ivoire.

MATERIALS AND METHODS

Selection of Study Zones

The study zones were selection criteria: accessibility in all seasons and the willingness of the farmers to participate to the study. The population density was less than 1 inhabitant km^{-2} and cotton was the predominant crop at more than 80 % on plots with an area of < 5 ha. The average interannual rainfall varied between 1,055 and 1,483 mm (Dekoula *et al.*, 2018).

The average annual temperature fluctuates between 29 and 30 °C. The vegetation was made up of dense wooded and degraded shrubby savannahs. The most common rocks were heterogeneous biotite granites and volcano- sedimentary schists. The relief varied between 300 m and 700 m. The soils of the zones were essentially Ferralsols and Gleysols (Diomandé, Loua Barthélémy *et al.*, 2016).

Figure 1 illustrates the "Savanes' District", the cotton growing zone of northern Côte d'Ivoire where the study was run. This work was conducted at the end of the 2019/2020 campaign in the Bagoué, Poro and Tchologo regions.

Data Collection

Soils were sampled from six localities: Boron (8.41 N, -5.58 W), Boundiali (9.53 N, -6.48 W), Diawala (10.11 N, -5.48 W), Ferkessédougou (9.58 N, -5.20 W), Kasséré (8.83 N, -6.22 W) and Korhogo (9.46 N, -5 .63 W). On each plot, a random composite sampling from 0 - 20 cm depth was made with four elementary samples taken under cotton fields.

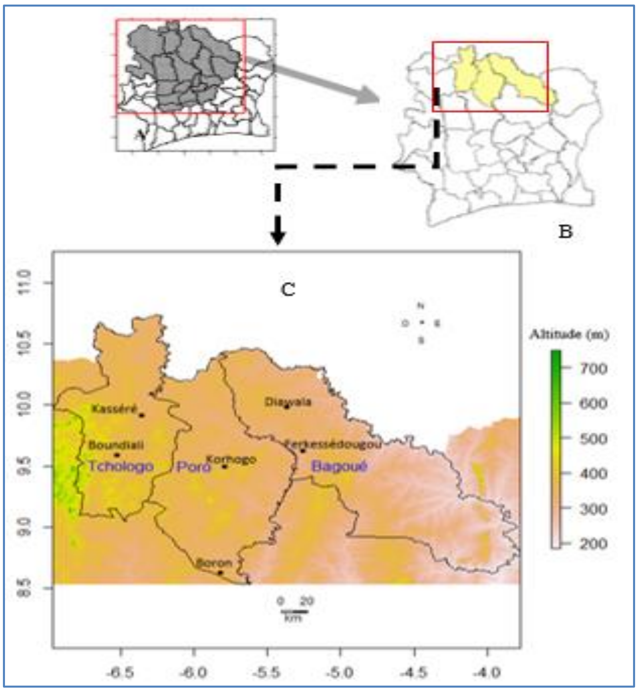

Figure 1: Location of study zones in Côte d'Ivoire, using Raster Graphics Algorithms
A: Côte d'Ivoire, B: cotton basin, C: Savanah Districts, Bleued: regions

Samples Treatment and Analysis

The soil fertility indicators were chosen according to previous works (Ama *et al.*, 2022; Ballot *et al.*, 2016; Kouadio *et al.*, 2018). The samples taken were air-dried and passed through a 2 mm mesh sieve and analysed in the laboratory for particle size, pH and the contents of nitrogen, assimilable phosphorus (P_2O_5), potassium, calcium, magnesium and sodium. The particle size was determined by the Robinson pipette method *(Pauwels et al.*, 1992). The pH was determined using a pH meter from a suspension of soil and distilled water in a 1:2.5 soil:water ratio. Nitrogen was determined by the Kjeldahl method. The available phosphorus was determined by the Olsen method. The exchange complex (Ca^{2+}, K^{+}, Mg^{2+} and Na^{+}) was assayed by atomic absorption spectrophotometry with ammonium acetate buffered at pH 7 and by the Kjeldahl method of the NH^{4+} ions resulting from the washing of the excess acetate of ammonium with alcohol and saturation of the complex with Na^{+} ions provided by a 10 % NaCl solution (CEC).

The interpretation of the current acidity (pH_{H2O}), the deficit in saturation of the soils absorbent complex by the alkaline-earth cations (Ca^{2+} and Mg^{2+}) and the alkali cations (Na^{+} et K^{+}), was carried out using the pH classification scale (Arrouays *et al.*, 2012) and indicative value of soils nutrients content (Table I).

Data Analysis

The data analysed included geographical coordinates (Latitude and Longitude) soil physical (Clay, Coarse and fine silts, Coarse and Fine sand) and chemical (pH, soils organic carbon, N, C/N ratio, P, CEC, Ca/(Mg+K) ratio, Sum of base cation and saturation rate) parameters.

The data were submitted to an analysis of mean at p = 0.05 (ANOM) ((Roy & Son, 2014) using the statistical software Minitab 17. Thereafter, a multivariable analysis was carried out to assess the relationship among variables and individuals. Soil clustering was conducted with the hierarchical ascending classification, to assure sustainable management recommendation. The clustering procedure used complete linkage, and a correlation coefficient distance of 50% similarity.

Table I: Classification scales of soil chemical content

Elements	critical values critiques				
	Very low	**Low**	**Normal**	**High**	**Very high**
N (g kg^{-1})	< 0.5	0.5 - 1	1 - 1.5	> 2.5	
P_2O_5 (mg kg^{-1})	< 15	15 - 25	25 - 50	> 100	
SOC (g kg^{-1})	< 0.5	0.5 - 1	1 - 1.5	> 2.5	
K (cmol+ kg^{-1})	< 0.1	0.1 - 0.15	0.15 - 0.40	>15	
Ca (cmol+ kg^{-1})	< 1.0	1 - 2.5	2.5 - 3.5	>7.0	
Mg (cmol+ kg^{-1})	< 0.5	0.5 - 1.0	1.0 - 1.5	>3.0	
CEC (cmol+ kg^{-1})	< 2	2 - 3	3 - 8	8 - 15	>15

Source: (Assa, 2005). OC: organic carbon

RESULTS

Actual Acidity and Soil Chemical Properties Variation in Cotton-Grown Soils the Study Zone

The soils of the six locations were slightly acidic to neutral (6.45 <pH_{H2O} <7.12). The analysis of mean of pH_{H2O} did not reveal a significantly different from the overall mean. The neutral pH was observed at Diawala and the acidic cotton-grown soil was found at Korhogo (Table II).

Soil organic carbon (SOC) content varied significantly among the sites: SOC content was significantly higher in Diawala with 1.8 g kg^{-1} while it had the lowest value of 0.7 g kg^{-1} in Boundiali. Relatively to the classification scale, SOC was high in Diawala and Boron, normal in Ferkessédougou, Kasséré and Korhogo, and low in Boundiali (Figure 2).

The total nitrogen content was very low in Boundiali and Korhogo, low in Boron and Ferkessédougou, normal in Diawara and Kasséré. The statistical analysis showed a significant difference between Diawala soil N content and the overall mean. The lowest of total soil nitrogen content was 0.07 g kg^{-1} at Boundiali and the highest at Diawala (Figure 2).

The soil assimilable phosphorus contents in Boron, Diawala and Ferkessédougou were very low while the ones of Boundiali and Kasséré were normal with 29 and 30 mg kg^{-1}, respectively.

There was a significant difference between some C/N ratios' means and the overall mean (Figure 2). The C/N ratios varied from 10 to 17, with the lowest and the highest in Kasséré and Boron, respectively.

Table II: Means' values of soils' acidity organic matter and chemical content of six cotton-grown zones

Locations	pH	C/N	P (mg kg^{-1})	$\frac{Ca^{++}}{K^{+} + Mg^{++}}$
Boron	6.60 b	17.00 a	12.00 b	2.28 b
Boundiali	6.65 b	10.00 b	28.50 b	1.45 b
Diawala	7.12 b	11.25 a	09.00 b	2.42 b
Ferkessédougou	6.85 b	11.00 b	10.00 b	2.34 b
Kasséré	6.75 b	10.00 a	33.30 b	2.17 b
Korhogo	6.45 b	11.11 b	23.25 b	3.44 b

Figures followed by “a” were statistically different from the overall mean and those followed by “b” were not

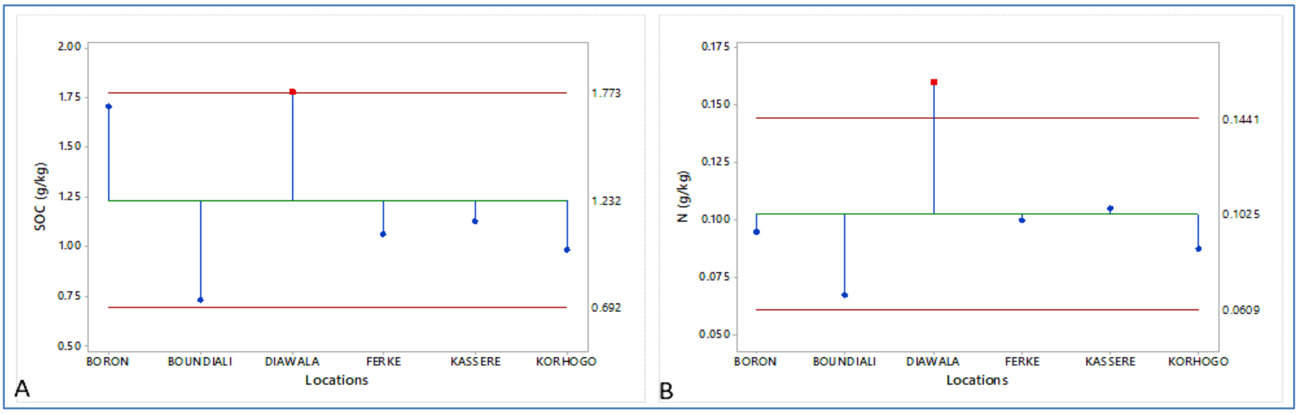

Figure 2: Means’ values of soil organic carbon (A) and nitrogen (B) of six cotton-grown zones

Exchange Complex

The analysis of mean of $\frac{Ca^{++}}{Mg^{++}+K^{+}}$ ratio did not show a significant difference among sites. It varied from 1.45 at Boundiali to 3.44 at Korhogo (Table II). Contrarily, the $\frac{Ca^{++}}{Mg^{++}}$ ratio showed significant difference among soils from the different localities. The highest mean value was observed at Korhogo with 4.30 and the lowest at Diawala with 3.18 (Figure 3).

The cation exchangeable capacity of soils varied from 5.64 cmol kg^{-1} to 15.32 cmol kg^{-1}, observed in the soils from Ferkessédougou and Kasséré, respectively (Figure 3). The base saturation, was significantly higher in Boron’s cotton-soils and lower in Kasséré with 59.40 % and 26.40 % (Figure 3).

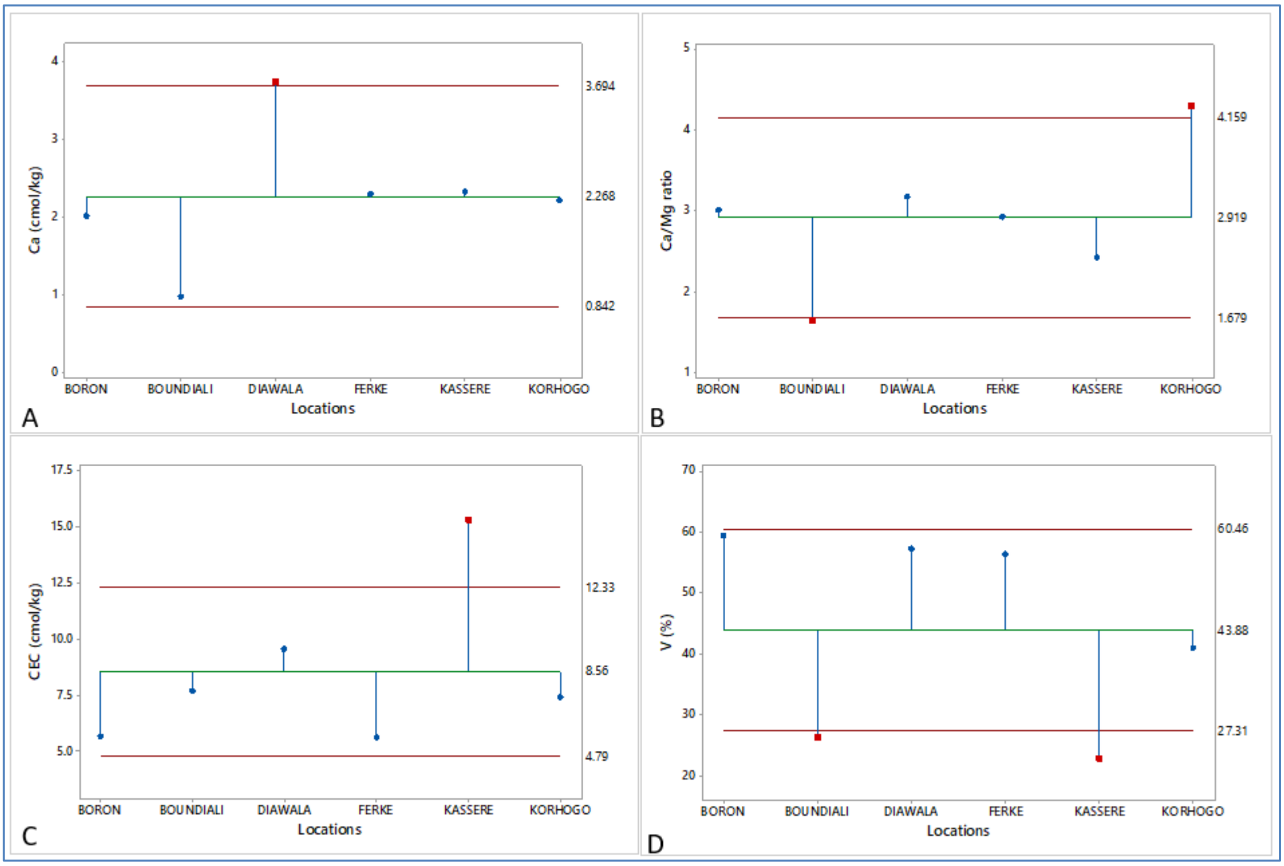

Figure 3: Means’ values of cotton-grown soils calcium content (A), Ca/Mg ratio (B), cation exchange capacity (CEC, C) and base saturation (V, D).

Soil Particles and Textures

The analysis of the granulometric parameters showed that the sand content means of cotton- grown soils from Kasséré and Korhogo were significantly different form the overall mean of 600.7 g kg^{-1}. Clay content of the cotton-grown soils of Korhogo was the lowest level with 93.250 g kg^{-1} while the one Kasséré was the highest with 183.750 g Kg^{-1}. Relatively to the silt content of the cotton-grown, none of the means was significantly different from the overall mean. Moreover, the soil textures varied from Sandy loam to Loamy.

Table IV: Soil particles content means' values of cotton-grown soils of study zones (g kg^{-1})

Locations	Clay	Silt	Sand	Texture
Boron	131.250 b	208.250 b	660.500 b	Sandy loam
Boundiali	144.250 b	279.500 b	576.250 b	Sandy loam
Diawala	167.500 b	268.500 b	564.000 b	Sandy loam
Ferkessédougou	120.000 b	301.250 b	578.750 b	Sandy loam
Kasséré	183.750 a	364.825 b	451.425 b	Loam
Korhogo	093.250 a	133.500 b	773.250 a	Sandy loam

Figures followed by "a" were statistically different from the overall mean and those followed by "b" were not.

Cluster Analysis of Variables

Clustering analysis was conducted to assess the relationship among the variables sharing 50% of similarity. The final partition showed 4 clusters. The Cluster 1 included the geographical coordinate latitude and the assimilable P. The cluster 2 comprised the geographical coordinate longitude, pH, SOC, N, Ca, S and V. concerning the cluster 3, it regrouped the contents of clay, coarse silts, fine silts and the CEC. The cluster 4 assembled the coarse sands, fine sands and the C:N ratio (Figure 4). This analysis also revealed that clusters 2 and 3 grouped variables which shared high similarity percentage (> 60%).

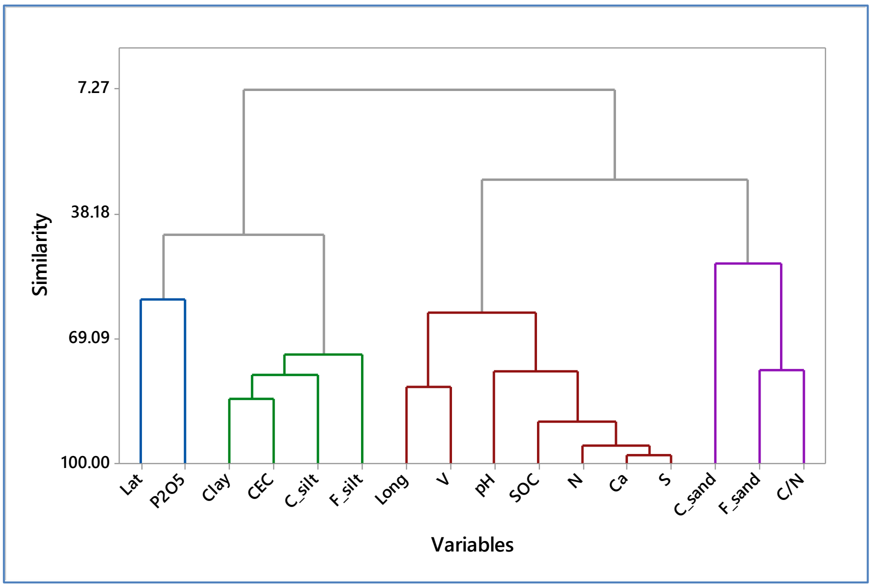

Figure 4: Ascending hierarchical classification dendrogram of cotton-grown soils variables

Cotton-grown soils were grouped with the principal component analysis (PCA), using the meaningful variables of clusters 2 and 3. The first two components well separated the six cotton-grown soils: soils of Boundiali were in quadrant A, Kasséré in quadrant B, Korhogo in quadrant C and, Diawala and Ferke in quadrant D. However, only the four cotton-grown soils of Korhogo were well grouped in the same quadrant. For Boundiali, Kasséré, Diawala and Ferke, only three soils belonged to the same quadrant (Figure 5). The soils from Boron scarted in three quadrants: one in quadrant A, two in C and one in D. Furthermore, only the soil of Kasséré occupied quadrant B.

DISCUSSION

This study was conducted to diagnose six cotton-grown soils of the cotton growing zone of northern Côte d'Ivoire. As any plant, cotton growth is dictated by soil physical, chemical biological properties. Under natural condition, soil pH is an important property that influences many biogeochemical processes, which regulates nutrient availability for the plant (Neina, 2019). Most of the plants have optimal growth when the soil pH is between 6 and 7, because the majority of nutrients are assimilated in this pH zone. Soil pH of the studied sites varied from 6.45 to 7.12, implying that soil pH condition is met for optimum availability of soil major nutrients.

The chemical analysis results of the studied cotton-grown soils revealed a relative normal organic carbon level. This could be explained by the organic amendments, which increase the SOC content on the soil surface, since cotton is cultivated in the savannah climate where soils are fragile in terms of fertility.

The rapid mineralization, in a dominant sandy soil, does not maintain an adequate amount of nutrients at the soil (sub) surface because of susceptible leaching, and then infer their availability for plants uptake and development. Consequently, mineral fertilisation only could not improve sustainably its production (Koulibaly *et al.,* 2009).

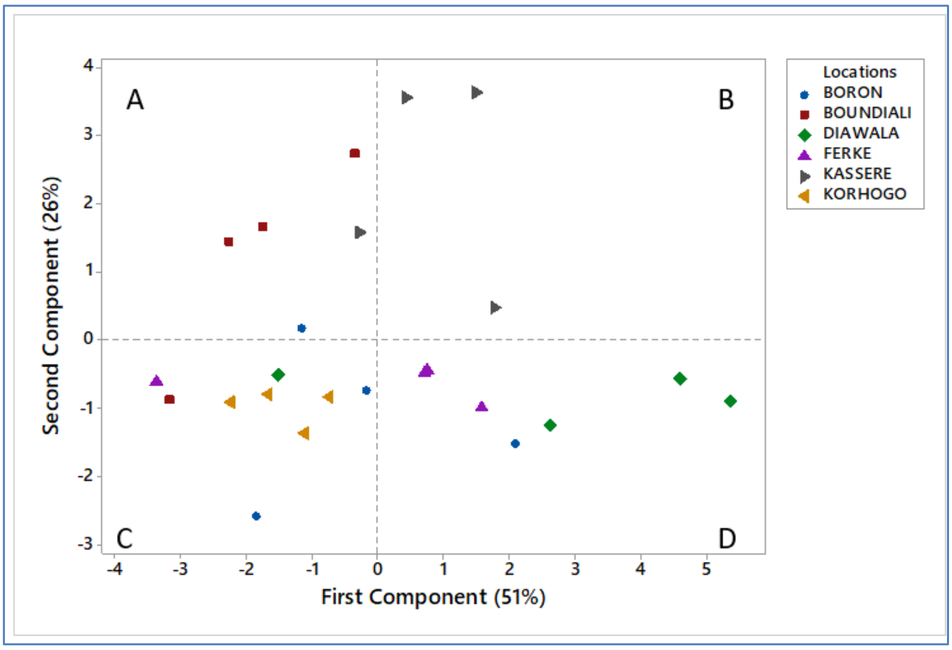

Figure 5: Homogeneous grouping of cotton-grown soils

It is therefore necessary to bring, periodically, about 25 Kg m^{-2} of compost in order to approach 5% of organic matter contents.

Cotton-grown soil had deficiencies in macronutrients such N and P. The total nitrogen was low in the majority of the cotton-grown soils studied. Soil nitrogen content, in sub-Saharan Africa, is one of limiting factors of crop yields while its sustainable management is a dilemma (Masso *et al.,* 2017). N deficiency affects equally vegetative and reproductive growth of cotton (Ahmed *et al.,* 2020). Nitrogen deficiency results in severely reduced growth, smaller leaves, rapid yellowing of older leaves, because it enters into the composition of proteins, chlorophyll and enzymes essential to photosynthesis. Cotton takes in greatest amounts N and K, at least 200 kg ha^{-1} (Rochester *et al.,* 2012). However, continuous application of N fertilizer could lead to soil acidification and affect negatively cotton production severely (Ghimire *et al.*, 2021).

Furthermore, the assimilable phosphorus concentration was exaggeratedly low. It is well documented that phosphorus availability in tropical soils is subjected to many constraints, including parent material, degree of weathering, and climatic conditions, despite its total amount in the soil could be extremely high (Vilaça De Vasconcelos *et al.,* 2022). This could reduce root growth, plant flowering, production, fruits ripening and lint yield. P deficiency affects fruit production in cotton than vegetative growth (Amed *et al.,* 2020). It is therefore useful to explore ways to improve phosphorus availability through soil-P remobilizing using soil microorganisms' activities (Plassard *et al.*, 2015).

Moreover, the carbon to nitrogen (C/N) ratio, which varied from 10 to 17, indicated edaphic conditions for microorganisms' activities. Between 1 and 15, the C:N ratio indicates rapid mineralization and release of N occurs, which is available for plant uptake (Brust, 2019; Hien *et al.,* 2004). The rate of nitrogen release in to soil is inversely related to C:N ratio: the smaller the C:N ratio, the greater is the turnover of SOM, the more rapidly nitrogen will be released into the soil and increase the nitrogen pool.

The ploughing practices could also be the cause of the low nutrients content observed at the surface (0-20 cm depth), since it was reported that ploughing reduces the rate of SOC and N by breaking up soil aggregates through increased aeration, mineralization of organic matter (Peukert *et al.*, 2016).

The grouping using the PCA analysis revealed a particularity of cotton-grown soils of Kasséré: 3 out of 4 were assigned uniquely to a quadrant. These soils had the highest level of CEC and the lowest mean value of base saturation (V). This observation could explain the fact that the cotton-grown soils of Kasséré have their complex bound to fewer basic cations (Ca, Mg, K and Na). Except Soil from Korhogo, soil grouping revealed spatial variation within same agroecological zone.

As it was observed, cotton-grown soils showed deficiencies in more than one nutrient, aligning with previous review, which stated that most soils where cotton is grown commonly have deficiencies in at least one major nutrient (Rochester *et al.*, 2012). Consequently, for optimum production, fertilizers application is required. However, due to the inconveniencies of inorganic fertilizer application, farmers should be oriented toward organic amendments to replenish their soils.

CONCLUSION

Soil analysis is a key to substantial soil nutrients management and fertilization planning. The study revealed the importance to strategize cotton-grown soils fertilization, since soils fertility level was low. From the results, it was shown that soils nutrients maintenance should be done through organic amendments, preferably.

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