Nutrient Availability in the Surface Horizons of Four Tropical Agricultural Soils in Mali

M. Soumaré*, A. Demeyer, F.M.G. Tack & M.G. Verloo

Keywords: Soil fertility – Macro and micronutrient – Mali

Summary
Studies of nutrient availability are important for the understanding and the estimation of soil fertility in areas like West Africa, where low nutrient availability is still one of the major constraints for food production. Physico-chemical soil analyses were used to assess the fertility status of the surface horizon samples of four Malian agricultural soils, (Bougouni, Kangaba, Baguinéda and Gao abbreviated as Bgni, Kgba, Bgda and Gao). Soil texture was sandy loam for Bgni and Kgba, sandy clay loam for Bgda and loamy sand for Gao. Soil pH values varied from moderately acid for Bgda to neutral for the other sites. Organic carbon ranged from very low (for Gao) or low (for Bgni and Bgda) to medium (for Kgba). Total N, P and CEC were low for the four soils. Available contents of Fe and Mn in all soils, except Gao, were higher than the critical levels while available Cu and Zn contents (except in Kgba) were below or close to it. Results indicated that Kgba soil had a better macronutrient status for plant growth than the other sites.

Résumé
Disponibilité des éléments nutritifs dans les horizons superficiels de quatre sols tropicaux agricoles du Mali

Introduction
Soil fertility in Africa is under pressure as an increasing number of farmers attempt to make a living based on what the soil can offer to growing plants (28). Although many studies on soil fertility in Africa have been carried out by research institutions since the sixties, many agricultural areas are still not studied yet. Most small farmers face the lack of scientific basis for improving the productivity of their soils. According to the classification of soil nutrient balances for arable land of sub Saharian Africa of Stoorvogel and Smaling (29), Mali is one of the countries where even major fertilizer (N, P, K) application rate is low. Maintenance of soil fertility for sustained soil productivity requires proper knowledge of nutrient availability or soil physicochemical characteristics.

Agricultural soils of Mali have not been sufficiently documented and recent data on fertility status are almost not available. Besides that, there is a need for detailed soil micronutrient status in Mali where most of the studies (for e.g. 2, 37) have been made only on major elements.

Since a first estimation about the fertility status of the soils can be obtained by chemical analyses, analytical procedures described by Pauwels et al. (21) were employed to assess the plant availability of some essential nutrients such as Ca, Mg, K, P, Fe, Mn, Zn and Cu in the surface horizon of the four Malian agricultural soils. These procedures were chosen because they are relatively simple and within the
The main objectives of this study were to obtain good information about the nutritional capacity and intensity of major (P, Ca, Mg and K) and minor (Fe, Mn, Zn and Cu) nutrients and about some physical characteristics of the surface horizons of four Malian agricultural soils. These informations are used to give appropriate agronomic and environmental advice.

**Methods**

**Site description and sample collection**

Mali is a tropical country located in the Sahelian zone (from 10° to 25° N and 12° W, 4° E). Surface horizon samples were taken from four different cultivated soils that had developed under three different climatic zones (Figure 1).

The Bougouni (Bgni) (11°05’ S 7°27’ W) and Kangaba (Kgba) (11°55’ S 8°24’ W) soils had developed under the southern part of the Sudanian agroecological zone. Annual rainfall in Kgba ranges between 1100 mm to 1500 mm while in Bgni it varies from 1000 to 1300 mm (31). Baguinéda (Bgda) (12°23’ S 7°45’ W) had developed under the northern part of the Sudanian with annual rainfall varying between 750 mm to 950 mm. Gao (16°18’ N 0° GM) is situated in the northern part of Sahelian zone, very closed to the Sahara zone with 150 to 250 mm of rainfall (31). At Bgni site, cotton (Gossypium hirsutum L.), maize (Zea mays L.), and groundnut (Arachis hypogaea L.) are in rotation. For more than 8 years, the Kgba soil is used for sorghum (Sorghum bicolor L.), and sometimes vegetable productions. The Gao site usable for rice (Oryza sativa L.) (34).

**Physicochemical characteristics**

In the four studied soils, the sand fraction dominated (Table 1). Most of the surface horizons of the agricultural soils in West Africa contain more than 50 % of sand (4, 18, 19). This sandy dominance suggests that the soils are quite permeable to air, water, and roots, but they have low water holding capacity and poor capacity for storing plant nutrients. According to the soil textural triangle of FAO (8), soils were classified as sandy loam (for Bgni and Kgba), sandy clay loam (for Bgda) and loamy sand for Gao. Clay contents of Bgni and Gao were below the minimum level (12 %) required by Gaucher cited by Horgnies (10). This suggests that these soils are not strong in their structural stability and may be subject to a high erosion. The bulk densities were below the limit level of (1.9 g/cm3) where root growth is usually stopped (12).

Soil pH varied from moderately acid for Bgda to neutral for the other sites, according to the acidity classes given by Veldkamp (34). This is within an optimal range for growth of maize (Zea mays L.), groundnut (Arachis hypogaea L.) and rice (Oryza sativa L.) (34). According to Sys (30) pH value in Bgda soil (5.67) may indicate P, Ca, Mg, and Mo deficiency while at the other sites (> 5.6) trace elements (such as Fe, Mn, Zn, Cu and Co) deficiency may occur (34). pH values in the four soils indicate that there is no danger from either exchangeable Al or excess of carbonates (15).

The electrical conductivity was below 2 dS.cm⁻¹. According to the reference values of the United States capabilities of many laboratories in the developing countries.

**Analyses**

The different analyses were performed according to methods described by Pauwels et al. (21). Particle size distribution was performed by dry and wet sieving. Soil pH was measured potentiometrically (Orion model 4120A) in a ratio of 1/2.5 soil/water suspension after equilibration for 16 h. Bulk density was determined in the non disturbed samples. Electrical conductivity (EC) and water soluble sulfate were measured in a saturation extract. EC was measured with a Microprocessor Conductivity Meter (LF 537) while the water soluble sulfate by ion chromatography (Dionex 2000i/SP). The organic carbon was analysed by the Walkley and Black method. Total nitrogen was determined using a modified method of Kjeldahl. Cation exchange capacity (CEC) was determined after saturation of the sorption complex with 1M neutral (pH 7) solution of ammonium acetate. Extractable forms of Ca, Mg, Na, K, Fe, Mn, Zn and Cu were extracted with a buffered (pH 4.65) solution of 0.5 M NH₄OAc-0.02 M EDTA with a ratio of 1/5.

Exchangeable Ca, Na, and K were determined with flame emission photometry (Eppendorf Elex 6361). Mg, Fe, Mn, Zn and Cu contained in the different solutions were measured by atomic absorption (Varian SpectraAA10). Available P was extracted with 0.03 M H₂HPO₄+0.1 M HCl. Total P was extracted with 0.03 M H₂PO₄ + 0.1 M HCl. Total and available P were determined colorimetrically (Spectrophotometer, CE 373) using the Schuel method.

**Results and discussions**

**Table 1.** The electrical conductivity was below 2 dS.cm⁻¹. According to the reference values of the United States
Salinity Laboratory (27), salinity is not expected to affect plant growth. The total N was very low for three soils (Bgni, Bgda and Gao) and low for Kgba. In west and central Africa, levels of 0.125 to 0.2 % of total N are considered as satisfactory (7). Organic matter content was medium for Kgba, very low for Gao and low for Bgni and Bgda (30). Low organic carbon contents in these soils are related to their agricultural use, the very limited organic amendment, and to the fast decomposition of organic matter in the tropical conditions (22, 26). The High C:N ratio (20 - 25.7) confirmed the greater degree of breakdown of organic matter in the studied soils.

According to the reference values of the Laboratory of Soil, Plant and Water of Sotuba (Mali), available phosphorous was from medium (> 5 mg/kg) for Kgba, and very low (5 mg/kg >) for the other three soils (5).

Similar results were reported by many authors (23, 24, 33) for tropical ferric and hydromorphous soils. Retention or fixation of P with Fe might be the main reasons of low available P in Bgda (13). Available P in all soils (except Kgba) was below the critical levels (4-29 mg/kg) for rice growth given by Dobermann et al. (6). Comparison of total P contents (Table 1) to the data of nine topsoil from the savanna region of Ghana (20) showed high values but according to the Malian reference values (< 200 mg/kg), all soils contained low level of total P (5).

For tropical soils, Kang and Osiname (14) reported a critical extractable sulfate concentration of 8 to 10 g/kg in the surface soil. Using this criterion, all the soils in this study would be considered S deficient (Table 1).

Table 1
Physicochemical characteristics of the topsoils (0 - 10 cm layer)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Bgni</th>
<th>Kgba</th>
<th>Bgda</th>
<th>Gao</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granulometry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand (%)</td>
<td>74.6</td>
<td>60.8</td>
<td>50.6</td>
<td>81.5</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>16.4</td>
<td>26.2</td>
<td>27.4</td>
<td>6.8</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>9</td>
<td>13</td>
<td>22</td>
<td>11.7</td>
</tr>
<tr>
<td>Texturea</td>
<td>sandy loam</td>
<td>sandy loam</td>
<td>sandy clay loam</td>
<td>loamy sand</td>
</tr>
<tr>
<td>$\rho_b$ (mg/m$^3$)</td>
<td>1.6 ± 0.01</td>
<td>1.6 ± 0.05</td>
<td>1.5 ± 0.01</td>
<td>1.7 ± 0.02</td>
</tr>
<tr>
<td>$pH_{H_2O}$</td>
<td>6.5 ± 0.02</td>
<td>7.0 ± 0.02</td>
<td>5.7 ± 0.01</td>
<td>6.9 ± 0.02</td>
</tr>
<tr>
<td>EC* (µS/cm)</td>
<td>500 ± 18</td>
<td>488 ± 11</td>
<td>174 ± 11</td>
<td>1843 ± 32</td>
</tr>
<tr>
<td>N total (%)</td>
<td>0.042 ± 0.000</td>
<td>0.057 ± 0.004</td>
<td>0.049 ± 0.002</td>
<td>0.019 ± 0.001</td>
</tr>
<tr>
<td>Organic C (%)</td>
<td>1.1 ± 0.1</td>
<td>1.5 ± 0.1</td>
<td>1.0 ± 0.2</td>
<td>0.5 ± 0.1</td>
</tr>
<tr>
<td>Total P (mg/kg)</td>
<td>131 ± 10</td>
<td>236 ± 32</td>
<td>100 ± 5</td>
<td>114 ± 3</td>
</tr>
<tr>
<td>P Available (mg/kg)</td>
<td>1.3 ± 0.2</td>
<td>5.4</td>
<td>0.8 ± 0.1</td>
<td>2.7 ± 0.3</td>
</tr>
<tr>
<td>Extractable SO$_4^-$ (mg/L)</td>
<td>9 ± 0.3</td>
<td>7 ± 0.2</td>
<td>6 ± 2.0</td>
<td>41 ± 4.0</td>
</tr>
</tbody>
</table>

Data are mean ± standard deviation of six replicates. aAccording to the FAO soil textural triangle (Soil Resources, Management and Conservation Service Land and Water Development Division, Rome 1990). *Measured in the saturation extract. EC means electrical conductivity.

In accordance with the sandy texture and the low organic matter contents, CEC values (Table 2) were low (25).

Table 2
Cation exchangeable capacity (CEC), exchangeable bases (E.B), and exchangeable cation ratios in the topsoils (0 - 10 cm layer)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Bgni</th>
<th>Kgba</th>
<th>Bgda</th>
<th>Gao</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEC (cmol / kg)</td>
<td>2.2 ± 0.40</td>
<td>4.6 ± 0.07</td>
<td>3.1 ± 2</td>
<td>3.0 ± 0.05</td>
</tr>
<tr>
<td>E. B. (cmol / kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K$^+$</td>
<td>0.107 ± 0.00</td>
<td>0.223 ± 0.01</td>
<td>0.070 ± 0.01</td>
<td>0.10 ± 0.01</td>
</tr>
<tr>
<td>Na$^+$</td>
<td>&lt; 0.040</td>
<td>&lt; 0.040</td>
<td>&lt; 0.040</td>
<td>0.19 ± 0.01</td>
</tr>
<tr>
<td>Ca$^{2+}$</td>
<td>1.24 ± 0.07</td>
<td>2.93 ± 0.07</td>
<td>1.12 ± 0.05</td>
<td>1.80 ± 0.08</td>
</tr>
<tr>
<td>Mg$^{2+}$</td>
<td>0.55 ± 0.01</td>
<td>1.39 ± 0.01</td>
<td>0.65 ± 0.01</td>
<td>1.06 ± 0.07</td>
</tr>
<tr>
<td>Ca/Mg</td>
<td>2.3</td>
<td>2.1</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Ca/K</td>
<td>11.6</td>
<td>13.1</td>
<td>16.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Mg/K</td>
<td>5.1</td>
<td>6.2</td>
<td>9.3</td>
<td>10.6</td>
</tr>
</tbody>
</table>

Data are mean of six replicates ± standard deviation. < 0.040 means below detection limit.
Defoer et al. (4) reported similar results for three major soil types in the southern Mali. Low CEC could be explained by the dominance of kaolinite in the clay fractions and of iron oxides. The dominance of kaolinite and iron oxides of the surface horizon of some Malian soils was reported by N’Diaye et al. (18) and Traoré (32). Low CEC values indicate that the studied soils may have a limited capacity to retain nutrients, specially cations and may be subject of a high risk of leaching (26).

**Exchangeable Ca, Mg, K and Na**

Exchangeable cations followed the normal order (Ca> Mg> K> Na) for all agricultural soils (17). The relative high exchangeable Ca content is in agreement with Veldkamp (34) and may indicate a near neutral pH which is desirable for most plants, microorganisms and good for soil structure. According to the norm of interpretation given by Gaucher cited in Hincourt (9), exchangeable K varied from very low (for Bgda) or low (Bgni and Gao) to medium (Kgba) (Table 2). Veldkamp et al. (35) and IER (11) reported similar results. However, exchangeable K in all soils (except Bgda) were within the critical levels (0.1 – 0.4 cmol/kg) given by Wopereis et al. (37) for rice growth (Oryza sativa L.). The Bgni, Bgda and Gao soils were low in exchangeable Ca and Mg while Kgba was medium (Gaucher cited in Hincourt (9)). Low exchangeable Ca, Mg and K in Bgda is not surprising since it is an acid soil and submitted to double cropping system. Low exchangeable Ca, Mg and K at Bgni could be explained by the low input of organic fertilizers as compared to Kgba which received every year farm compost as fertilizer. Medium level of exchangeable Ca and Mg at Gao could be related to the aridity of the climate under which the risk of leaching is very low.

The Ca/Mg ratios of the four soils (Table 2) were within the optimal range of 1.5 to 5 given by Boyer (3). The Ca/K ratios in all soils except Bgni were higher than the upper limit level of 12 given by Boyer (3). This indicates that only the Bgni soil had an optimal Ca/K ratio. According to the optimal range (2- 5) of Mg/K ratio given by Euroconsult (7), only the Bgni soil presented a good equilibrium between Mg and K (Table 2).

In general, the soils have a low natural fertility as indicated by the low content of total N and P, organic matter and exchangeable bases. Since the utilization of mineral fertilizers by the farmers of the different sites is financially prohibitive, the studied soils must be fertilized adequately by-products (crop residues, manure and farm compost) that are available in the different regions in order to complement their inherent fertility so as to supply the necessary nutrients to meet the requirements of field crops such as rice, maize, cotton and sorghum.

**Micronutrients availability (Single extraction with NH₄OAc EDTA pH 4.65)**

The NH₄OAc EDTA extractable or available trace metal contents were compared to reference values given by Verloo (36) for the same type reagent. In all soils, available Fe were higher than the critical levels given by Verloo (36) and above the minimum amount (> 4.5 mg/kg) required by *Sorghum bicolor* L. (16) (Table 3).

Available Fe followed this order Bgda> Kgba> Bgni> Gao. The highest amount of available Fe in Bgda soil is not surprising because this soil is used for rice (*Oryza sativa* L.) production under irrigation and that condition may create a reduction of Fe³⁺ to Fe²⁺ (13). Available Mn was above the critical level (10 mg/kg) given by Verloo (36) for Bgni, Kgba and Gao and low for Gao. Netherless, available Mn obtained in Gao was still higher than the critical level proposed by Cox cited in Adriano (1). The amount of available Zn extracted in all soils (except Kgba) were below critical level for plant growth (36). Available Cu was below (for Bgni and Gao) or close (for Kgba and Bgda) to the critical levels given by Verloo (36). The results suggest that Cu deficiency may occur in all soils, Zn deficiency in three soils (Bgni, Bgda and Gao), and Mn in Gao.

Interpretation of data was difficult because of the absence of reference levels for Malian soils and also in the literature there are no static values of interpretation. In order to evaluate the real uptake of nutrient further studies are required.

**Conclusions**

The particle size distribution revealed that the sand fraction dominated in the four soils studied and that might indicate low water retention capacity. Three of the four (Bgni, Kgba, and Gao) soils studied had neutral reaction while Bgda was acidic. All the four soils selected for the present study were low in total N and P, available S and Cu, and CEC. The CEC values

<table>
<thead>
<tr>
<th>Element (mg/kg)</th>
<th>Bgni</th>
<th>Kgba</th>
<th>Bgda</th>
<th>Gao</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>36 ± 4</td>
<td>42 ± 3</td>
<td>70 ± 8</td>
<td>30 ± 1</td>
</tr>
<tr>
<td>Mn</td>
<td>12 ± 0.4</td>
<td>21 ± 3</td>
<td>17 ± 0.1</td>
<td>6 ± 1</td>
</tr>
<tr>
<td>Zn</td>
<td>1.4 ± 0.5</td>
<td>5 ± 1</td>
<td>1.5 ± 0.3</td>
<td>1.1 ± 0.3</td>
</tr>
<tr>
<td>Cu</td>
<td>1.3 ± 0.1</td>
<td>2.0 ± 0.2</td>
<td>2.0 ± 0.1</td>
<td>1.6 ± 0.4</td>
</tr>
</tbody>
</table>

Data are mean of six replicates ± standard deviation.
showed also that in the four soils high leaching of nutrients may occur. The total organic carbon, available P and exchangeable Ca, K, and Mg were low for three soils (Bgni, Bgda and Gao) and medium for Kgba. Three of the four soils (Kgba, Bgda and Gao) were also characterised by imbalance between Ca and K and between Mg and K. Mg deficiency might occur in the Gao soil. Considering the different characteristics studied, Kgba showed a better nutrient status than the other soils. The relatively high nutrient level at Kgba might be related to the use of manure and farm compost. An oriented program for the improvement of the productivity of the studied soils must supply N, P, K, Ca, Mg, Cu, S, organic carbon and Mn (for Gao only). Since the utilization of mineral fertilizers by the farmers of the different sites is financially prohibitive, and the low input of organic fertilizers appeared to be a common problem for the four sites, the improvement of the productivity of the studied soils should be done towards the utilization of by-products (crop residues, manure and farm compost) that are available in the different regions. But, prior to the use of farm compost or manure at Bgni, Kgba and Gao sites, the effects of the chosen organic material on the redistribution of the micronutrients (such as Fe, Mn, Zn and Cu) should firstly carefully be examined. In Bgda, more attention should be given on retention of P.

Acknowledgements

The authors wish to thank Mr. Mamadou Koné and Dramane Coulibaly (respectively Chef et agent de la section centrale de la CMDT de Bougouni), Mr. Ousmane Touré and his family (farmer in Bougouni), Ben Mohamed (Directeur de la section Opération Haute Vallée du Niger à Kangaba), Mr. Togola (ingénieur in Kangaba), Mr. Abdoulaye Mama Touré (Département des eaux et forêts à Kangaba), Mr. Maré Doumbia (farmer in Kangaba), Mr. Bouno Kampo (ingénieur in Baguinéda), Mr. Seydou Traoré (1er adjoint au commandant de cercle de Gao) and Mr. Boncana Touré (Chef SSRA de Bagoundié).

Literature


M. Soumaré: Malian, Master in soil science, specialty soil chemistry and ecopedology. Master in agronomy, specialty agrochemistry and pedology. Researcher at the Department of Applied Analytical and Physical Chemistry of the University of Ghent since 1997.

Demeyer: Belgian, Doctor, Assistant at the Department of Applied Analytical and Physical Chemistry of the University of Ghent from October 1994 until February 2001.

F.M.G. Tack: Belgian, Professor at the Department of Applied Analytical and Physical Chemistry of Ghent University since 1998.

M.G. Verloo: Belgian, Professor at the Department of Applied Analytical and Physical Chemistry of Ghent University since 1988.