Investigation of Soil Status in Degraded Soils from Tantalum Mining in Gatumba, Rwanda

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Different soil properties from Gatumba Mining Area were assessed to characterize them and contribute in setting up practices for soil restoration. The present study was conducted to assess the soil status in degraded soils from tantalum mining in Gatumba. Nine soil profiles which were prepared in 2009 during dry season were sharpened and soils from all visible horizons were sampled. Soil analysis was performed in the soil laboratory at National University of Rwanda. Results showed that the active soil pH was lower in technosol developed on schist (4.8) and higher in technosol composed by pegmatite dump (5.61) and ranged from slightly acid (5.61) to acidic (4.73). Acid saturation was lower in strongly disturbed fluvisol (3.4%) and higher in technosol composed by pegmatite (10.78%) while base saturation was lower in cambic-fluvisol (37.5%) and higher in technosol composed by pegmatite (89.3%). However, a significant difference (p=0.012) only observed in base saturation between soil profiles. In general, soils affected by mining had low base saturation and higher acid saturation than unaffected. Therefore, recommendation of more soluble amendment such as lime and dolomite would improve the soil pH and provide macronutrients like Ca²⁺ and Mg²⁺.

Key words: Acid saturation, Base saturation, Gatumba mining area, Rwanda and Soil pH

INTRODUCTION

Since many decades, soil acidity has been a major growing-limiting factor for plants in many parts of the world (Mc Lean, 1976; Kamprath; 1978; Adams, 1978, 1981). Estimates of the total area of the top soils affected by acidity throughout the world vary from 3.777.10⁹ to 3.950.10⁹ ha, representing approximately 30% of the total land area of the world. The total area affected by subsoil acidity is estimated as 2.918.10⁹ ha, meaning that approximately 75% of the acid soils of the world suffer from subsoil limitations due to acidity (Zdenko, 2003). Rwanda, most arable soils are acidic and poor in vital macronutrients (Nitrogen, Phosphorus and Potassium) for plant growth. The lack of these elements leads to continuous decline of agricultural production (Mutuwiseingabo et al, 1987). Many factors have contributed to soil acidity include erosion, overcultivation, anthropogenic activities such as mining which deteriorate soil fertility through soil degradation by removing the topsoil’s which are rich in soil nutrients and replaced either by invaluable cropland or bare wasteland. Soil acidity is a major limiting factor of soil productivity (Mc Lean, 1976; Kamprath, 1978; Adams, 1978; 1981). Most of Rwandan soils are acid with pH levels below 5 and low base saturation of about <35% as confirmed by Mutuyimana (2011).
In addition, soils become acidic during geological evolution and when their parent materials were acid and poor in base cation (Ca\(^{2+}\), Mg\(^{2+}\), K\(^{+}\), Na\(^{+}\)) or because these elements have been removed from the soil profile by normal rainfall or the harvesting of crops (Kamprath and Foy; 1972). In addition, soil acidification is frequently inevitable in agriculture. Soils of Gatumba mining area are not only influenced by parent material, climate, relief and cultivation, coltan mining activities but also climate that may cause several changes in physical and chemical properties of soils leading to soil degradation or soil fertility depletion through erosion and leaching of basic cation. Soil developed on mine spoils are shallow and in early stages of the development characterized by the deficiencies of soil organic matter and nutrients as other reclamation area. The most cultivated annual crops in mine spoils includes cassava and sweet potato (Anika, 2008). It has also shown that mining affects both the living and non-living things through the physical modification of the soil environment (Adewole and Adesina, 2011).

The present study was designed to assess the soil status in degraded soils from tantalum mining in Gatumba during the rainy season. The assessment of different soil properties helped us to generally characterize the soils from that study area and contribute in setting up practices for soil restoration.

**MATERIALS AND METHODS**

**Site description**

The study was conducted in 2012 in Gatumba mining District (GMD) (figure 1) Western Province of Rwanda and is located next to the Nyabarongo River between the longitudes 29°37' and 29°40' E and the latitudes 1°53' and 1°56'S. With an average altitude of 1,700 m above sea level (ASL), the highest hilltops are about 1,900 m ASL while the Nyabarongo River reaches an altitude of about 1,370 m ASL in the area (Reetsch, 2008). The natural soils (soils which have developed outside of the mining areas) of the GMD are representative for the tropical highlands of Rwanda. Typical Soil Reference Groups found in GMD include Lixisols, Nitisols, Cambisols, Gleysols and Umbrisols (IUSS Working Group WRB, 2006).

In Gatumba, the open cast mining has disturbed large areas of land and has formed entire landscapes with deep escarpments owing to the high price of tantalum and the increasing demand in the world market. The annual rainfall in Gatumba varies between 1,300 and 1,500 mm. This abundant rainfall has totally leached the soils that have developed from poor parent materials such as sandstone, quartzite, quartzophyllite and granite. The average annual temperature of the area is between 15 and 18°C mainly due to high altitude (2,100 m above sea level).

![Figure 1: Location of the investigation area Gatumba Mining District (red circle), Rwanda (Paulmann, 2012)](image_url)
The vegetation of the study area is mainly derived from savannah with some reforested patches on the top of the hills (Ndabanize et al., 2007). Three agricultural seasons have been developed. Two correspond with the rainy seasons. The third season (from June to September) allows a third harvest of crops cultivated in poorly drained valleys (Verdoot and van Ranst, 2003).

Geographically, Rwanda is divided into two parts: the western and the eastern part. The mountainous topography of western Rwanda where GMD located, originates from the eastern rim of the Albertine Rift Valley which is part of the Great Rift Valley. The rift valley escarpment also forms the watershed between the Congo River and the Nile in the highlands of Rwanda (Reetsch, 2008). At the western border the largest freshwater body of the country, the Kivu Lake, is located and Nyabarongo River flows through the tropical highlands of Rwanda. While, the Eastern Rwanda is characterized by less mountainous landscapes. Swamps and small lakes are spread over the eastern regions and along the border to Tanzania. The Akagera River marks the border to Tanzania.

Soil Sampling and Analyses

Forty-four soil samples were collected from Gatumba mining area in 9 soil profiles which were prepared in 2009 during dry season were sharpened and soils from all visible horizons were sampled. (P1) Technosol on mine spoil, (P2) Technosol on schist, (P3) Technosol overlaying Gleysol on pegmatite material, (P4) Technosol without soil development (pegmatite dump from coltan mining), (P5) Cambic fluvisol, (P6) cambic Fluvisol, (P7) Fluvisol, (P8) Fluvisol covered by colluvium and (P9) strongly disturbed Fluvisol. These samples were taken during rainy season from nine soil profiles; all soils were wet during the sampling process. Soil samples were taken by auger, from 40-45 cm of soil depth, from four profiles.

The soil samples were air-dried and passed through a 2-mm sized sieve. The following soil characteristics were determined: (i) pH water (1:2.5 soil/water ratio) and pH KCl (1:2.5, soil/1N KCl solution ratio); (ii) Exchangeable cations (Ca, Mg, K, and Na) extracted with 1M NH₄OAc buffered to pH 7 (Jones, 2001) and the elements determined using atomic absorption spectrophotometer (AAS) and exchangeable aluminum was obtained according to 1N KCl extraction (Cottenie et al., 1982).

Effective cation exchange capacity (ECEC) was calculated as the sum of basic cations in addition to exchangeable Al using the laboratory methods of soil and plant analysis as described by Okalebo et al., (2002).

Data analysis

The data collected from field samples was entered in Microsoft Excel and analyzed using GenStat (5th edition) software at 5% level of significance. Soil data parameters were subjected to “one-way analysis of variance (ANOVA) in Randomized blocks”. The results were presented in the form of table.

RESULTS AND DISCUSSION

Results

The mean values for soil pH, A.S, B.S, ECEC, and exchangeable bases are presented in Table 1. These results from the laboratory analyses showed that the active soil pH was statistically lower in technosol developed on schist (4.8) and statistically higher in technosol composed by pegmatite dump (5.61). Acid saturation was statistically lower in strongly disturbed fluvisol (3.4%) and statistically higher in technosol composed by pegmatite (10.78%). While base saturation was statistically lower in cambic-fluvisol (37.5%) and statistically higher in technosol composed by pegmatite (89.3%).

Table 1: Table of mean values for the pH, A.S, B.S, ECEC, Na⁺, K⁺, Ca²⁺ and Mg²⁺

<table>
<thead>
<tr>
<th>Profile No</th>
<th>pH (water) (%)</th>
<th>A.S (Cmol/kg)</th>
<th>B.S (Cmol/kg)</th>
<th>ECEC (Cmol/kg)</th>
<th>Na⁺ (Cmol/kg)</th>
<th>K⁺ (Cmol/kg)</th>
<th>Ca²⁺ (Cmol/kg)</th>
<th>Mg²⁺ (Cmol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>5.06</td>
<td>10.78</td>
<td>45.91</td>
<td>3.62</td>
<td>0.15</td>
<td>0.33</td>
<td>1.88</td>
<td>0.58</td>
</tr>
<tr>
<td>P2</td>
<td>4.83</td>
<td>6.51</td>
<td>65.12</td>
<td>4.09</td>
<td>0.49</td>
<td>0.36</td>
<td>2.04</td>
<td>0.81</td>
</tr>
<tr>
<td>P3</td>
<td>5.03</td>
<td>4.33</td>
<td>54.11</td>
<td>6.16</td>
<td>0.16</td>
<td>0.41</td>
<td>3.35</td>
<td>1.32</td>
</tr>
<tr>
<td>P4</td>
<td>5.61</td>
<td>3.33</td>
<td>89.33</td>
<td>2.78</td>
<td>0.12</td>
<td>0.25</td>
<td>1.78</td>
<td>0.53</td>
</tr>
<tr>
<td>P5</td>
<td>4.98</td>
<td>5.33</td>
<td>37.91</td>
<td>5.10</td>
<td>0.20</td>
<td>0.26</td>
<td>3.02</td>
<td>0.94</td>
</tr>
<tr>
<td>P6</td>
<td>5.36</td>
<td>4.80</td>
<td>51.63</td>
<td>5.22</td>
<td>0.16</td>
<td>0.32</td>
<td>3.19</td>
<td>1.28</td>
</tr>
<tr>
<td>P7</td>
<td>5.47</td>
<td>6.83</td>
<td>54.77</td>
<td>6.62</td>
<td>0.29</td>
<td>0.36</td>
<td>3.36</td>
<td>2.14</td>
</tr>
<tr>
<td>P8</td>
<td>5.14</td>
<td>6.55</td>
<td>75.41</td>
<td>4.42</td>
<td>0.22</td>
<td>0.28</td>
<td>2.61</td>
<td>0.98</td>
</tr>
<tr>
<td>P9</td>
<td>5.15</td>
<td>3.42</td>
<td>80.30</td>
<td>5.22</td>
<td>0.16</td>
<td>0.62</td>
<td>2.71</td>
<td>1.56</td>
</tr>
<tr>
<td>Fpr</td>
<td>0.12</td>
<td>0.36</td>
<td>0.01</td>
<td>0.35</td>
<td>0.71</td>
<td>0.19</td>
<td>0.62</td>
<td>0.01</td>
</tr>
<tr>
<td>CV (%)</td>
<td>6.90</td>
<td>64.20</td>
<td>33.50</td>
<td>37.80</td>
<td>144.70</td>
<td>49.00</td>
<td>50.60</td>
<td>43.10</td>
</tr>
<tr>
<td>LSD</td>
<td>0.55</td>
<td>5.87</td>
<td>30.71</td>
<td>2.89</td>
<td>0.54</td>
<td>0.26</td>
<td>2.17</td>
<td>0.73</td>
</tr>
</tbody>
</table>

A.S: Acid saturation; B.S: Base saturation; ECEC: Effective cation exchange capacity.
DISCUSSION

Soil pH

Values for pH water varied in the range of 4.73 to 5.61 for Technosols and between 4.67 to 5.57 for Fluvisols. By using the standard norms of Landon (1991) for tropical soils and those of Mutwewingabo and Rutunga (1987) for the soil of Rwanda, these soils' pH ranges from slightly acid to acidic soils. Normally, Tropical soils are generally acidic except soils formed under the influence of volcanic eruption which have a medium basic pH except in cultivated soils and mining site, the pH begins to decrease from alkaline to weakly acid if the soil is strongly affected by those activities.

The low pH observed in the study area is a result of different factors including the presence of high precipitation over long period, high weathering intensity in the tropical highlands of Rwanda, the acid parent material (sericite schist or sandstone) of the soils and, the soil is also washed during mining activities so that many base cations are carried away by water leaving hydrogen cations on soil colloids Ndoli A., (2013).

A low pH is responsible for the mobilization of Al and Fe which promotes the immobilization of P through the formation of stable Fe and Al phosphates. This may further increase P deficiency in crops (Scheffer and Schachtsch, 2002). In addition, according to Landon (1991), the low soil pH enhances un-favorable chemical reactions like denitrification, aluminium and manganese toxicity and P deficiency. The direct effects of H⁺ ion on plant growth are difficult to determine in acids soils (Moore, 1974). In addition, acidity in the soil damage plant root and color (Islam et al., 1980). Once the roots are prolonged exposed to low pH (<4), their capacities for nutrients absorption are reduced (Adams, 1984).

Therefore, liming could be an important measure for increasing soil fertility in the respective soils. Significance of pH lies in its influence on availability of soil nutrients solubility, of toxic nutrients elements in the soil physical breakdown of roots cells, CEC soils whose colloids (clay/humus) are pH dependent, and on biological activity. When the pH rises from acid to nearly neutral, P becomes more available (Moore, 1974).

Exchangeable cations and base saturation

The amounts of exchangeable cations in soil are an indication of the nutrient status or the level of soil fertility. The result of exchangeable cations analyses (Table 1) show that for Technosol, the content of Ca²⁺ ranges between 1.78 to 3.48 cmol /kg of soil, the content of K⁺ ranges between 0.25 to 0.5 cmol/kg of soil, the content of Mg²⁺ ranges between 0.53 to 1.29 cmol /kg of soil and the content of Na ranges between 0.11 to 0.73 cmol /kg of soil. For Fluvisol, the content of Ca²⁺ ranges between 1.23 to 5.6 cmol /kg of soil, the content of K⁺ ranges between 0.25 to 1.28 cmol /kg of soil, the content of Mg²⁺ ranges between 0.6 to 2.68 cmol /kg of soil and the content of Na⁺ ranges between 0.1 to 0.36 cmol /kg of soil. Based on the norms of Mutwewingabo and Rutunga (1987) for the soils of Rwanda, the contents of calcium are low to moderate, whereas the contents Mg²⁺ are very low to moderate. The content of Na⁺ is very low, whereas the content of K⁺ is classified as low to very high. The low content of Mg²⁺ is explained by the low pH of the tropical soils. The base saturation percentage is the ratio of the sum of basic cations (Ca²⁺, Mg²⁺, K⁺, and Na⁺) and the total CEC times 100. The base saturation percentage has an important significance compared to the acid saturation. It is frequently used as an indicator of soil fertility status, and criteria for soil classification (Brady and Weil, 2002).

In addition, according to Brady and Weil (2001), the base saturation of the soil is defined as the percentage of the soil’s CEC (on a charge equivalent basis) that is occupied by these cations. A high base saturation (>50%) enhances Ca²⁺, Mg²⁺, and K⁺ availability and prevents soil pH decline. Low base saturation (<25%) is indicative of a strongly acid soil that may maintain Al³⁺ activity high enough to cause phytoxicity. The base saturation ranged between 43.18 to 89.33% for Technosol and between 18.36 to 93.52% for Fluvisol. Based on the norms of interpretation cited by Mutwewingabo and Rutunga (1987) base saturations were classified as strongly low to very high. In acid soils the BS may vary between 24 and 92 % (Igwe et al., 2004). Consequently, BS values of the investigated soils of the Gatumba Mining District were typical for acid soils.

Exchangeable Ca

Exchangeable calcium ranges from 1.23 to 5.6cmol/kg. The proposed critical level of Ca²⁺ for most crops was 5.0 cmol/100g (Marx et al., 1996). The mean of all those collected samples contained lower levels of calcium than required.

Exchangeable Mg²⁺ and K⁺

Exchangeable Mg²⁺ ranged from 0.53 to 2.68cmol/kg. The proposed critical value in most crops was 2cmol/kg (Schwartz and Coralles, 1989). About 87% of all horizons has less Mg²⁺ than required and these could limit the crop growth. Therefore, to have maximum crop yields, supplemental Mg²⁺ is needed where necessary. The results showed that soils from the study area are not deficient in exchangeable K⁺as their values were ranged from 0.25 to 1.28 cmol/kg which were higher than required. It has been confirmed by Anderson, 1973, who said that most plants grown in East Africa requires 0.20 cmol/kg of K⁺ in soils for their optimal growth. The application of K⁺ fertilizers should only be recommended to maintain the K⁺ level in the continuously cropped soils.
Acid saturation

The acid saturation ranged from 10.3 to 18.36%, the analysis of variance showed a non-significant difference among treatments at level of probability of 0.360 due to homogeneous change among those samples. The acid saturation is a good indicator of soil infertility status in acid soils and can help to assess the level of concentration and probably the activity of Al and H+ cation compared with the activity of base saturation. Soil acidity may result from parent materials that were acidic and naturally low in basic cations (Ca²⁺, Mg²⁺, K⁺, and Na+) or because these elements have been leached from the soil profile by heavy rains (Fageria et al., 1990a). The exchangeable and soluble Al³⁺ ions react with water (hydrolyze) to form H⁺ ions. For this reason, Al³⁺ and H⁺ together are considered acid cations. Soil acidity may also develop from exposure to the air of mine spoils containing iron pyrite (FeS₂) or other sulfides, (Brady and Weil, 2002).

Crop fertilization with ammonia or ammonium fertilizers can result in soil acidification. In addition, acidity may also be produced by the decomposition of plant residues or organic wastes into organic acids. Acidification is a natural process involved in soil formation and is higher in humid tropical regions and a major constraint for crop production in that region. By constraint, in drier regions, soil retains enough basic cations and prevents the solubility, attraction of acid cations and is an alkaline soil (pH >7) (Donahue et al., 1983).

Effective Cation Exchange Capacity

ECEC higher than 4 cmol/kg in soils are known to be good to counter the leaching of cations (Brady and Weil, 2002), and the 69.6% of the investigated soils were susceptible to lose their bases by leaching. Fluvisols present a relatively high content of ECEC due to their neutral pH condition which doesn’t impair the availability of nutrients, (Driessen and Dudal, 1989) and the low ECEC content was observed in Technosol which is highly lixiviated soil. The lack of soil profile formation of Technosol didn’t facilitate the cations holding process. Most of tropical soils have ECEC lower than 4cmol/kg and this problem can be addressed by increasing the ECEC through organic matter application and/or liming.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Soil samples from Gatumba mining area (District of Ngororero, Western Province of Rwanda) were either developed in coltan mine spoils or outside of the mined areas. Nine soil profiles were described and soils from each horizon analyzed to assess the soil status in degraded soils from tantalum mining in Gatumba. Results showed that all samples are strongly to moderately acidic. The pH obtained in most of the plough horizons were not very favorable for crops since the ideal pH for many crops range approximately between 6.2 to 7.5. In most cases if not all, pH is below 5.5, the range in which Al toxicity had risen. The Al levels found might not be high enough to make a significant negative effect to plant growth. Thus, the applications of both liming materials and organic manure to increase soil pH and enhance nutrients availability are inevitable. This will also help in the improvement of soil structure, water holding capacity, cation exchange capacity, provide a slow-release fertilizer and serve as microbial inoculums. Alternatively, OM addition can be used to reduce Al³⁺ toxicity by binding the Al³⁺ ions in OM complexes. Due to the removal of base cation (Ca²⁺, Mg²⁺, K⁺, Na⁺) from the soil profile by normal rainfall or the harvesting of crops, about 87% of all horizons has less Mg²⁺ than required and it could be a limiting factor for plants growth. While, exchangeable K⁺ was high in soils due to high weathering of minerals rich in K⁺ (feldspar, mica) accompanied by continuous release of K⁺. The immediate attention to replenish the already depleted soils was recommended. Results showed no significant difference in soil pH and acid saturation between soil profiles. However, a significant difference (p=0.012) in base saturation was found between soil profiles. However, a significant difference in soil pH and acid saturation between soil profiles. However, a significant difference (p=0.012) in base saturation was found between soil profiles. In general, soils affected by mining had higher base and acid saturation than the ones unaffected. Technosol substrates, especially pegmatite coming from mining activities had higher pH compared to the soils which were not affected by mining. Therefore, agricultural planning must consider the assessment of soil status to come-up with realistic decision on the present land use and fertility management.

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