Spatial distribution of basic exchangeable cations under different land uses in soils of Hamelmalo, Eritrea

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Abstract
The study was conducted at two sites; Hamelmalo Agricultural College and Basheri watershed area in sub Zoba Hamelmalo, Keren to determine the status of basic exchangeable cations (Ca, Mg, K and Na) under different land uses and their relationship with physico-chemical properties of soils. Global Positioning System based soil samples were collected randomly from different land use systems, cultivated (cereals and horticulture) and non-cultivated open wood lands. The pH values ranged from neutral to strongly alkaline and electrical conductivity values were found to be non-saline in nature. The textures of majority of the surface samples were found sandy loam. Availability of exchangeable Ca⁺⁺, Mg⁺⁺, K⁺ and Na⁺ in surface soils of all land uses varied from high to very high, moderate to high, very low to low and very low to moderate, respectively. Exchangeable K⁺ showed highly significant positive correlation (p<0.01) with clay content. However exchangeable Ca⁺⁺ contents in soil was positively and significantly correlated (p<0.05) with pH, clay, silt and negative significant correlation (p<0.05) with BD. Mg⁺⁺ had positive significant correlation (p<0.05) with clay content and negative significant correlation (p<0.05) with sand.

Keywords: Calcium, magnesium, potassium, sodium, soil texture, bulk density, correlation

Low and declining soil fertility in Eritrea, is caused by continuous cultivation where soil nutrient replenishment, by whatever means, are too low to mitigate the process of soil nutrient mining, and the soil fertility is not restored by new inputs (Shisanya et al., 2009). Crop yield per unit area of land has declined drastically, and the vegetation cover is virtually noted to be decreasing at an alarming rate. In many parts of the country, grass has ceased to grow due to the loss of grass seeds and due to the depletion of top soil even when there is sufficient amount of rain fall (Haile et al., 1998). For an effective correction of basic exchangeable cations nutrient deficiency in the field, it is necessary to understand the reasons of deficiency in the soil. Knowledge of spatial and vertical distribution of basic exchangeable cations in soil is helpful in understanding the inherent capacity of soil to supply these nutrients to plants and their downward movement in soil. Little or no work has been done on the status of basic exchangeable cations under different land uses in Hamelmalo. Thus, keeping in view the importance of these land uses and inadequate information available, the present study entitled “Spatial distribution of basic exchangeable cations under different land uses in soils of Hamelmalo, Eritrea” was conducted to determine the status of basic exchangeable cations (Ca, Mg, K and Na) under different land uses and their relationship with physico-chemical properties of soils.

MATERIALS AND METHODS

Site Description
The study was conducted in Zoba Anseba,sub Zoba Hamelmalo at two adjacent sites namely Hamelmalo Agricultural College (HAC) and Basheri Watershed Area (BWA) at 15°52'21" N and 38°27'42" E, latitude and longitude, respectively, and elevation of 1285 m a.s.l. The study area had a semi arid climate with past fourteen year’s average annual rainfall of 424 mm yr⁻¹. Highest mean monthly temperature was in May (34.7°C) and the lowest in January (11.0°C).

Collection and Preparation of Soil Samples
Study area was surveyed using Global
Positioning System (GPS) tools and overlaid with swiztopo satellite image of HAC. Stratified random sampling design were carried out, where the samples within each stratifying unit were randomized. Following the general site selection, representative fields were selected from each land use type, cultivated (cereal and horticultural) and non-cultivated open woodlands (OWL). Collected soil samples were processed and stored in cloth bags for analysis.

Soil Analysis

The analysis of physical and chemical properties of soils was carried out at Hamelmalo Agricultural College and National Agricultural Research Institute (NARI).

Data Analysis Correlation Studies

Correlations were worked out to establish the relationship between soil properties and basic exchangeable cations using IBM SPSS package as per the procedure outlined by Gomez and Gomez (1984) to reveal the magnitudes and directions of relationships between selected soil fertility parameters and physco-chemical properties.

RESULTS AND DISCUSSION

Mechanical Separates

Comparing all land use systems lower values of surface clay fractions were observed than sand and silt fractions (Table 1). The low clay content of these soils might be due to the removal of clay particles from the surface soils either by wind or runoff water. Similar results were reported by Kaistha and Gupta (1994). The results further revealed that the surface soils of individual profiles contained less amount of clay content as compared to the clay content of sub-surface soils of cereal cultivated (CC) and horticulture cultivated (HC) areas. Jaiyeoba (2003) also indicated that the clay contents of deeper depths increased with the increase of cultivation year. However, the percentage clay content of surface soils of open wood lands (OWL) was higher than that of sub-surface soils. This might be due to the fact that the cultivated soils are subject to the erosion by wind or water whereas forest soils are relatively protected due to vegetation cover and availability of OM.

Bulk and Particle Density (BD and PD)

Perusal of the data with respect to bulk density in table 1 showed that irrespective of land use types, the lowest value of BD 1.33 g cm\(^{-3}\) and the highest 1.78 g cm\(^{-3}\) were observed in OWL and CC land uses, respectively. The low bulk density in OWL might be due to the addition of organic matter in comparison to the adjacent cereal and horticultural land uses. Higher Bulk density in cultivated land than forest areas was also reported by Woldeamlak and Stroosnijder (2003) and Jaiyeoba (2003). Regarding particle density, the minimum value of 2.39 g cm\(^{-3}\) was obtained in OWL soils whereas the maximum value of 2.69 g cm\(^{-3}\) was found in cereal cultivated soils of HAC.

Total Porosity (TP)

The average values of TP percentage of surface soils showed that the highest porosity was found in OWL followed by HC and CC land uses. The maximum mean value of percentage TP in OWL might be due to the presence of relatively higher amount of clay and organic matter content.

Soil Reaction (pH) and Electrical Conductivity (EC)

As per the limits for soil pH given by Bruce and Rayment (1982), the data with respect to surface soil reaction under CC, HC and OWL use systems showed that majority of soils were neutral to moderately alkaline in reaction. According to Richards (1954) salinity ranges for soil based on EC\(_e\), all the soil samples fall in the normal EC range indicating that salinity is not at all a problem in these soils.

Exchangeable Calcium

Content of exchangeable Ca\(^{++}\) in CC, HC and OWL uses varied from 17 to 28, 18 to 21 and 17 to 29 cmol(+) / kg, with mean values of 24.17 ± 4.12, 19.5± 2.12 and 23± 8.45 cmol (+)/kg, respectively. When comparing the three land uses, the highest (28
Cmol (+)/kg) exchangeable Ca$^{++}$ content was observed in CC land uses at BWA and the lowest (17 cmol (+)/kg) was found in CC at BWA and OWL uses of HAC. It was observed that content of exchangeable Ca$^{++}$ in CC land uses was 16.67% high and 83.33% of samples were recorded very high and in HC fields these were 50% high and 50% were in very high range, similarly in OWL use all the samples had higher exchangeable Ca$^{++}$ content.

Exchangeable Magnesium

The Exchangeable magnesium (Mg$^{++}$) content in CC, HC and OWL areas varies from 2 - 7, 4- 5 and 6 - 7 cmol (+)/kg, respectively. The highest (7 cmol (+)/kg) was found in CC and OWL uses at HAC and the lowest (2 cmol (+)/kg) exchangeable Mg$^{++}$ content was found in CC soils at BWA. The mean values of cultivated, horticultural and OWL uses were 5.33±1.75, 5.0±0 and 6.5±0.71cmol (+)/kg, respectively. The value of exchangeable Mg$^{++}$ content in CC areas was found as 16.67% moderate and 83.33 % high and all the soil samples in HC and OWL uses were qualified for higher content of exchangeable Mg$^{++}$. The medium to very high levels of Mg$^{++}$ in the soils suggest that the soils have sufficient natural Mg$^{++}$ supplies for crop growth in the study sites.

Exchangeable Potassium

The Exchangeable potassium (K$^{+}$) content was found highest (0.26 cmol (+)/kg) in OWL and the lowest (0.07 cmol (+)/kg) in CC land use at BWA. The relatively higher content of K$^{+}$ in the OWL than cereal cultivated land was in agreement with the results reported by Mesfin (1996). In general in all land uses availability of exchangeable K$^{+}$ ranged from very low to low. The lower content of available K$^{+}$ might be attributed to less abundance of Illite - a potassium rich mineral in these soils (Mesfin, 1996). Exchangeable K$^{+}$ levels below 0.2 cmol (+)/kg suggested that a plant response to the application of K$^{+}$ fertilizer was possible, particularly where heavy removal of K by harvesting or grazing occurs (Hazelton and Murphy, 2007). The ranges of mean exchangeable K$^{+}$ values observed in this study showed that K$^{+}$ was below the critical levels (0.38 cmol (+)/kg) for the production of most crop plants as indicated by Barber (1984). Generally, the lower exchangeable K$^{+}$ contents in the CC lands than in the OWL area might be due to its continuous losses in the harvested parts of the plants from the cultivated areas. The fore mentioned findings had also considered these factors and the application of acid forming fertilizers as major factors affecting the distribution of K$^{+}$ in soil systems mainly enhancing its depletion especially in tropical soils (Barber, 1984).

Exchangeable Sodium

The exchangeable sodium (Na$^{+}$) in CC, HC and OWL uses ranged from 0.06 to 0.54, 0.54 to 0.68 and 0.27 to 0.28 cmol (+)/kg, with an average value of 0.25±0.18, 0.61±0.10 and 0.28±0.01cmol (+)/kg, respectively. The highest (0.68 cmol (+)/kg) content of exchangeable Na$^{+}$ was found in HC based land use system. Whereas the lowest (0.06 cmol (+)/kg) value of exchangeable Na$^{+}$ was obtained from CC land uses at BWA. Based on Metson (1961) levels of exchangeable cations, 16.67% and 50% of soil samples from CC soils were ranged very low and low, respectively. Whereas, 33.33% and 100% samples from CC and HC were found in moderate range, respectively. Similarly in OWL uses all samples showed low in exchangeable Na$^{+}$ content. This low to moderate value of Na$^{+}$ could be considered as better for soil because higher concentration of Na$^{+}$ deteriorates soil structure and make the soil liable for soil erosion and devoid of beneficial organisms. In general according to Metson (1961) availability of exchangeable Ca$^{++}$, Mg$^{++}$, K$^{+}$ and Na$^{+}$ in all land uses varied from high to very high, moderate to high, very low to low and very low to moderate, respectively.

Relationship between Soil Physico-Chemical Properties and Exchangeable Cations

Potassium content of the soil irrespective of land use showed positive and significant correlation (p<0.05) with OM (r= 0.744*) and total porosity (r= 0.756*) showed highly significant positive correlation (p<0.01) with clay content (r= 0.843**). Singh et al., (2012) also reported similar results. Moreover the data showed that exchangeable potassium content was negatively and significantly
correlated (p<0.05) with sand (r = -0.665*) and particle density (r = -0.693*). However exchangeable potassium content gave highly negative significant

Table 1. Soil physco-chemical parameters and their methods of analysis

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>Methodology</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil texture</td>
<td>% (w/w)</td>
<td>Hydrometer</td>
<td>Van Reeuwijk (1992)</td>
</tr>
<tr>
<td>Bulk density (BD)</td>
<td>g cm⁻³</td>
<td>Core sampling</td>
<td>Landon (1991)</td>
</tr>
<tr>
<td>Particle density (PD)</td>
<td>g cm⁻³</td>
<td>Volumetric flask method</td>
<td>Ryan et. al., (2001)</td>
</tr>
<tr>
<td>Chemical Parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH (1:5)</td>
<td></td>
<td>pH meter</td>
<td>Ryan et. al., (2001)</td>
</tr>
<tr>
<td>EC (1:5)</td>
<td>dS m⁻¹</td>
<td>Conductivity meter</td>
<td>Ryan et. al., (2001)</td>
</tr>
<tr>
<td>Organic Matter (OM)</td>
<td>% (g g⁻¹)</td>
<td>Walkley and Black</td>
<td>Ryan et. al., (2001)</td>
</tr>
<tr>
<td>Exchangeable K⁺</td>
<td>cmol kg⁻¹</td>
<td>Extraction with ammonium acetate</td>
<td>Rhoades (1982)</td>
</tr>
<tr>
<td>Exchangeable Na⁺</td>
<td>cmol kg⁻¹</td>
<td>Extract by titration with EDTA</td>
<td>Richards (1954)</td>
</tr>
<tr>
<td>Exchangeable Mg²⁺</td>
<td>cmol kg⁻¹</td>
<td>Extract by titration with EDTA</td>
<td>Richards (1954)</td>
</tr>
</tbody>
</table>

Table1. Range and Mean values of surface (0-20 cm) soil physical properties under different land uses

<table>
<thead>
<tr>
<th></th>
<th>Sand, %</th>
<th>Silt, %</th>
<th>Clay, %</th>
<th>BD, g cm⁻³</th>
<th>PD, g cm⁻³</th>
<th>TP, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereal cultivated (CC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>58-65</td>
<td>23.7-36.7</td>
<td>2.00-11.3</td>
<td>1.54-1.78</td>
<td>2.65-2.69</td>
<td>34.00-42.38</td>
</tr>
<tr>
<td>Mean</td>
<td>62.05±3.11</td>
<td>30.18±5.49</td>
<td>6.27±3.95</td>
<td>1.63±0.10</td>
<td>2.66±0.03</td>
<td>39.24±3.20</td>
</tr>
<tr>
<td>Horticultural Cultivated (HC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>45.45-52.5</td>
<td>35.5-38.8</td>
<td>12-15.8</td>
<td>1.36-1.54</td>
<td>2.48-2.58</td>
<td>40.31-45.17</td>
</tr>
<tr>
<td>Mean</td>
<td>48.95±5.02</td>
<td>37.15±2.33</td>
<td>13.9±2.69</td>
<td>1.45±0.13</td>
<td>2.53±0.07</td>
<td>42.74±3.44</td>
</tr>
<tr>
<td>Open woodland (OWL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>51.00-52.5</td>
<td>26-26.6</td>
<td>21.5-22.4</td>
<td>1.33-1.35</td>
<td>2.39-2.40</td>
<td>43.52-44.56</td>
</tr>
<tr>
<td>Mean</td>
<td>51.75±1.06</td>
<td>26.3±0.42</td>
<td>21.95±0.64</td>
<td>1.34±0.01</td>
<td>2.40±0.01</td>
<td>44.04±0.74</td>
</tr>
</tbody>
</table>
Table 2. Range and Mean values of surface (0-20 cm) soil chemical properties under different land uses

<table>
<thead>
<tr>
<th></th>
<th>pH (1:5)</th>
<th>EC(1:5)</th>
<th>OM</th>
<th>K⁺</th>
<th>Ca++</th>
<th>Mg++</th>
<th>Na⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dS/m % cmol(+)/kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cereal Cultivated (CC)</td>
<td>Range</td>
<td>7.15-8.29</td>
<td>0.03-0.10</td>
<td>0.17-0.47</td>
<td>0.07-0.21</td>
<td>17.28</td>
<td>2-7</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>7.51±0.41</td>
<td>0.05±0.03</td>
<td>0.35±0.11</td>
<td>0.13±0.05</td>
<td>24.17±4.12</td>
<td>5.33±1.75</td>
</tr>
<tr>
<td>Horticultural Cultivated (HC)</td>
<td>Range</td>
<td>8.06-8.37</td>
<td>0.13-0.17</td>
<td>0.961.23</td>
<td>0.18-0.25</td>
<td>18-21</td>
<td>4-5</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>8.22±0.22</td>
<td>0.03±0.15</td>
<td>1.10±0.19</td>
<td>0.22±0.05</td>
<td>19.5±2.12</td>
<td>2.00±0.00</td>
</tr>
<tr>
<td>Open Wood Land (OWL)</td>
<td>Range</td>
<td>7.48-7.56</td>
<td>0.07-0.09</td>
<td>0.74-1.29</td>
<td>0.21-0.26</td>
<td>17.29</td>
<td>6-7</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>7.52±0.04</td>
<td>0.08±0.01</td>
<td>1.02±0.39</td>
<td>0.24±0.04</td>
<td>23±8.45</td>
<td>6.5±0.71</td>
</tr>
</tbody>
</table>

Correlation with bulk density (r= -0.855**). On the other hand sand content had high negative correlation with OM (r = -0.871**) and EC (r= -0.782**) and showed negatively and significantly correlated with clay content (r= -0.674*). With regard to silt content of the surface soils, no significant positive or negative correlation was observed between surface silt content and OM and exchangeable cations as well. Clay content of the surface soils showed high significant positive correlation with total porosity (r=0.736**) and OM content (r= 0.735**). These results were in agreement with Burke et al., (1990). Moreover clay content of the surface soil had high significant negative correlation with bulk density (r= -0.870**), PD (r= -0.840**) and significant negative correlation with sand content (r= -0.674*). Particle density of the surface soil showed significant positive correlation with BD (r=0.798*) and showed high significant negative correlation (r= -0.794**) with OM of the surface soil. Chaudhari et al., (2013) reported similar results of high degree reverse correlation between organic matter and bulk density. Whereas BD of the surface soil showed highly significant negative correlation with TP (r= -0.930**) and OM (r= -0.725). Exchangeable magnesium content in the soils under study had positive significant correlation (p<0.05) with clay content (r= 0.716*). The exchangeable magnesium also gave negative significant correlation (p<0.05) with sand (r= -0.851*). These results were in line with the observations of Woomer et al., (1994). The exchangeable sodium content was found small but it had significant positive correlation (p<0.05) with electrical conductivity (r= 0.756*). However exchangeable calcium contents in soil positively and significantly correlated (p<0.05) with pH (r= 0.727*), clay (r= 0.736*), silt (r= 0.846*). CONCLUSION In general pH range was favorable for plant nutrient availability. Salinity was not at all a problem in the study area. OM content of the area was at low range which indicated that these soils were severely eroded, degraded and had low structural stability. The data regarding basic exchangeable cations showed that while considering all land uses together the value of exchangeable calcium (Ca++), magnesium (Mg++), potassium (K⁺) and sodium (Na⁺) ranged from 16 to 29, 2 to 7, 0.07 to 0.26 and 0.06 to 0.68 cmol(+)/kg soil, respectively. The result of high to very high level of both calcium and magnesium level of the study area, indicated that exchange complex of the soils was dominated by Ca++ followed by Mg++, K⁺ and Na⁺. These results were in agreement with the findings of Tuma (2007) on fluvial soils in Gamo Gofa zone, Ethiopia. Exchangeable K⁺ values were found below the critical levels (0.38 cmol (+)/kg) for the production of most crop plants as reported by Barber (1984).

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