Chemical characterization of a Fagus grandifolia subsp. mexicana forest soil

Acovedo-Sandoval OAI*, Ortega-Zavala EM³, Prieto-Méndez J¹, Prieto-García F² and Romo-Gómez CØ

¹Research Center for Earth and Material Sciences, Institute for Basic Sciences and Engineering. City of Knowledge. Pachuca-Tulancingo Highway km 4.5 Col. Carboneras. CP 42076, Pachuca, Hidalgo, Mexico.
²Center for Chemical Research, Institute for Basic Sciences and Engineering. City of Knowledge. Pachuca-Tulancingo Highway km 4.5 Col. Carboneras. CP 42076, Pachuca, Hidalgo, Mexico.
³Research Center for Biologica Research, Institute for Basic Sciences and Engineering. City of Knowledge. Pachuca-Tulancingo Highway km 4.5 Col. Carboneras. CP 42076, Pachuca, Hidalgo, Mexico.
⁴Institute for Agricultural Sciences, Universidad Autónoma del Estado de Hidalgo.

*Corresponding author. Email: acovedo@uaeh.edu.mx
Tel: +52 775 7533495. Fax: +52 777 17172000

ABSTRACT

Cloud forest in Mexico is one of the most fragile biomes, where in some species of Fagaceae family, play a key ecological role. Fagus grandifolia subsp. mexicana (Fgm) is an endemic species of tree in Mexico. In the state of Hidalgo, its population size has been reduced due to timber harvesting, overgrazing and its use for firewood, as well as its seeds being consumed by humans. This has placed it in danger of extinction, NOM-059-SEMARNAT-2010. The aim of this study was to evaluate the chemical characteristics of soil under a Fgm. The soils were characterized by: a pH which was strongly to extremely acidic; exchangeable bases, such as calcium, magnesium and potassium, which had low values. Thus the content of organic matter (OM) and phosphorus retention in soils was high and the cation exchange capacity (CEC) was low (average of 13.1 cmol + kg⁻¹). Geochemically, there was a significant shortage of Mg, Ca, Na, and K oxides, and the enrichment of Al₂O₃. The infrared spectrum (IR) of the organic layer showed polysaccharide structures, amide, ether, ester and carboxyl groups, and the IR of the soil showed kaolinite group minerals.

Key words: Cloud forest, infrared spectrum, Fagus grandifolia subsp. mexicana, organic matter, soil acidity.

INTRODUCTION

The importance of the chemical properties of soil for tree growth has been overlooked for decades, but in recent years, has gained considerable attention. The chemical characteristics of soils are indicators of the evolutionary processes that are taking place.

Vegetation plays a major role in determining the nature and properties of soils; when this is changed, the structure and function of the ecosystem is also altered, especially the bio-geochemical cycles of the surface horizon. Peña et al. (2005) reported that studies which characterize forest soils increasingly require more information to determine the function of the soil ecosystem, with biochemical properties becoming increasingly important in this type of research, since they are indicators of the quality and balance that exists in this environment. Godínez et al. (2007) conclude that there are certain relationships between plant population and some physical and chemical properties of soil, such as the accumulation of organic matter (OM), bulk density, cation exchange capacity, among others. These studies provide important information on soil development and forest structure. Aponte (2011) reports that knowledge regarding the interactions established between plants and the soils on which they grow is essential to understanding how these ecosystems function.

In Mexico, large areas of cloud forest have been lost due to widespread deforestation and conversion for agricultural purposes (livestock, coffee, sugar cane, corn and other crops) and for both rural and urban human settlements (Cayuela et al. 2006). A surface loss of about 50% since the sixties of mountain cloud forest and tall and mid-level evergreen forests was estimated by Challenger and Soberón (2008). The cloud forest occupies only 0.8% of the country; nevertheless, this forest contains 10% of the vascular flora of the country (Rzedowski, 1996). Due to this and the
excessive extraction of certain forest products, such as wood, wood charcoal (Haeckel, 2006) orchids, bromeliads, ferns, palms and fauna, these forests are globally considered a priority in terms of conservation, being centers of origin for important biodiversity and for the wide range of environmental services they generate.

Different vegetal associations of the Mexican cloud forest are represented by Fagus grandifolia subsp. mexicana (Fgm), which are the richest ecosystems due to the great variety of species by area. On a national level, Fgm is in danger of extinction (NOM-059-SEMARNAT-2010), with the population density also seen as being affected by the long life cycle of the species, where this tree produces seeds every seven years and their viability is delicate (Godínez et al., 2007). It is known that the fragments of Fgm at the states of Puebla, San Luis Potosí and some areas of Veracruz have been extinguished completely and some of the few forests that remain are at risk to become extinct.

The Fgm forest in the Medio Monte region in the municipality of San Bartolo Tutotepec, in Hidalgo Mexico (Figure 1) is a site of great pressure for indigenous communities. Since they are faced with a high degree of marginalization and poverty, they are forced to subsist on the overexploitation of natural resources. This leads to a rapid change in land use through excessive logging, where original surface loss is estimated to reach up to 60% (Villavicencio and Pérez, 2005). The Hidalgo stands of Fgm are proposed as reserve areas, given the relictual and endemic nature of this taxon, and therefore, the present study aimed at evaluating the chemical characteristics of soil under a forest of Fgm in order to generate elementary information, which will serve as a basis for future studies on their sustainable management to help conserve this species.

MATERIALS AND METHODS

Location and characteristics of the study area

The Fgm forest is found in the Otomi-Tepehua region of the municipality of San Bartolo Tutotepec, in Hidalgo, Mexico, occupying an area of two hectares with a Fgm density of 529 ha⁻¹. This forest, which is considered relictual (Villavicencio and Pérez, 2005) is located between coordinates 20°24'46" latitude north and 98°15'51" longitude west, at an average altitude of 1,840 m. The area is located within the physiographic province of Carso Huastec, with its lithology consisting of sedimentary rocks from the Mesozoic era of the Cretaceous period, and also consists of reef limestone, argillaceous limestone, limestone with flint, dolomite and shale. Its topography comprises steep-sloped sierras. The climate is warm, temperate-humid (A) C (fm), with an annual average temperature of 18°C, and annual rainfall of 1,800 mm (DOEH, 2001), conditions that are favorable for the development of forest.

Fieldwork and laboratory

The selection of the study area was made from a previous mapping study supplemented with tours of the area. Five representative sites within two hectares of natural forest of Fgm were chosen. The study area is moderately disturbed by anthropogenic activities. At each site, three subsamples of soil were collected at depths of 0-20, 20-40 and 40-60 cm, which were mixed and produced a sample composed of layers. These were taken to the laboratory where they were air dried and sieved through a 2 mm mesh for their respective chemical analysis.

The methods used to determine the chemical properties of each layer have been reported by USDA-NRCS (2004). The variables analyzed were: pH in water (1: 2.5) and in 1 N KCl (1: 2.5), cation exchange capacity (CEC), and exchangeable bases extracted with 1 N ammonium acetate with pH 7.0. They were analyzed by inductively coupled plasma emission spectrometry, using the Perkin Elmer 3000 Lambda 2S model. The organic matter (OM) was tested using the Walkley and Black method, with the phosphorus retention also analyzed (SEMARNAT, 2002). All analysis was performed in triplicate.

Total oxides were quantified by X-ray fluorescence with a sequential X-ray spectrometer (X SRS SIEMENS 3000). Characterization of organic and inorganic fraction was conducted using infrared spectroscopy (IR) on a Perkin Elmer FT-IR GXN Spectrum System.

RESULTS AND DISCUSSION

Table 1 shows the values obtained for some chemical properties of the soil. The pH (1: 2.5 in water) of the soil ranged from 4.0 to 5.3, strongly to extremely acidic, with a slight decrease in acidity with increased soil depth, except for point 4, which increased. Whereas, the KCl pH values were less than 4.8, indicating soil with moderate potential acidity and a low degree of saturation.

OM content is high (SEMARNAT, 2002) and decreases slightly with soil depth, a fact that is especially related to organic migration processes. The cation exchange capacity may generally be considered low (average 13.1 cmol·kg⁻¹), whereas the percentage of phosphorus retention in the soil is high in all layers exceeding 88%, because the phosphorus is immobilized by forming complexes with Fe and Al sesquioxides.

The high soil acidity presented in the study area restricts the development and productivity of plants, displaying severe problems with nutrient availability and aluminum toxicity (Al), which interferes with the taking, transportation and use of nutrients (Casierra and Aguilar;
**Figure 1.** The *Fagus grandifolia* subsp. mexicana forest in the Medio Monte region in the municipality of San Bartolo Tutotepec, in Hidalgo, Mexico.

**Table 1.** Chemical characterization of soils under *Fagus grandifolia* subsp. mexicana.

<table>
<thead>
<tr>
<th>Sample</th>
<th>pH: H2O (1:2.5)</th>
<th>pH: KCl (1:2.5)</th>
<th>OM %</th>
<th>NT %</th>
<th>C.E.C</th>
<th>Ca2+</th>
<th>Mg2+</th>
<th>K+</th>
<th>Na+</th>
<th>EB Cmol(+)/Kg</th>
<th>P retention(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1, 0-20</td>
<td>4.67</td>
<td>3.99</td>
<td>9.30</td>
<td>0.46</td>
<td>13.86</td>
<td>5.20</td>
<td>0.5</td>
<td>0.2</td>
<td>1.1</td>
<td>50.50</td>
<td>100</td>
</tr>
<tr>
<td>P1, 20-40</td>
<td>4.70</td>
<td>4.39</td>
<td>8.80</td>
<td>0.44</td>
<td>10.19</td>
<td>3.60</td>
<td>0.4</td>
<td>0.3</td>
<td>1.3</td>
<td>54.95</td>
<td>92</td>
</tr>
<tr>
<td>P1, 40-60</td>
<td>4.85</td>
<td>4.35</td>
<td>8.20</td>
<td>0.41</td>
<td>9.66</td>
<td>2.00</td>
<td>1.0</td>
<td>0.3</td>
<td>1.0</td>
<td>44.51</td>
<td>90</td>
</tr>
<tr>
<td>P2, 0-20</td>
<td>4.24</td>
<td>4.00</td>
<td>14.00</td>
<td>0.70</td>
<td>14.23</td>
<td>4.00</td>
<td>0.4</td>
<td>0.3</td>
<td>0.7</td>
<td>37.95</td>
<td>98</td>
</tr>
<tr>
<td>P2, 20-40</td>
<td>4.64</td>
<td>4.44</td>
<td>12.30</td>
<td>0.61</td>
<td>13.71</td>
<td>5.10</td>
<td>0.5</td>
<td>0.2</td>
<td>0.9</td>
<td>48.87</td>
<td>93</td>
</tr>
<tr>
<td>P2, 40-60</td>
<td>4.62</td>
<td>4.19</td>
<td>10.60</td>
<td>0.53</td>
<td>11.05</td>
<td>4.40</td>
<td>0.5</td>
<td>0.2</td>
<td>0.9</td>
<td>54.30</td>
<td>91</td>
</tr>
<tr>
<td>P3, 0-20</td>
<td>4.19</td>
<td>4.00</td>
<td>9.40</td>
<td>0.47</td>
<td>19.40</td>
<td>6.50</td>
<td>1.8</td>
<td>0.3</td>
<td>1.7</td>
<td>53.36</td>
<td>98</td>
</tr>
<tr>
<td>P3, 20-40</td>
<td>4.09</td>
<td>4.01</td>
<td>7.67</td>
<td>0.38</td>
<td>18.72</td>
<td>4.40</td>
<td>0.7</td>
<td>0.3</td>
<td>1.2</td>
<td>35.25</td>
<td>90</td>
</tr>
<tr>
<td>P3, 40-60</td>
<td>4.23</td>
<td>4.12</td>
<td>6.86</td>
<td>0.34</td>
<td>11.91</td>
<td>4.00</td>
<td>0.7</td>
<td>0.1</td>
<td>0.4</td>
<td>43.66</td>
<td>90</td>
</tr>
<tr>
<td>P4, 0-20</td>
<td>5.25</td>
<td>4.71</td>
<td>9.53</td>
<td>0.48</td>
<td>15.44</td>
<td>3.80</td>
<td>1.8</td>
<td>0.2</td>
<td>1.0</td>
<td>44.04</td>
<td>90</td>
</tr>
<tr>
<td>P4, 20-40</td>
<td>5.20</td>
<td>4.54</td>
<td>8.36</td>
<td>0.42</td>
<td>15.20</td>
<td>2.30</td>
<td>1.7</td>
<td>0.1</td>
<td>0.7</td>
<td>31.58</td>
<td>88</td>
</tr>
<tr>
<td>P4, 40-60</td>
<td>5.19</td>
<td>4.80</td>
<td>6.84</td>
<td>0.34</td>
<td>13.40</td>
<td>2.30</td>
<td>1.5</td>
<td>0.1</td>
<td>0.9</td>
<td>35.82</td>
<td>87</td>
</tr>
<tr>
<td>P5, 0-20</td>
<td>5.03</td>
<td>4.56</td>
<td>9.53</td>
<td>0.48</td>
<td>10.91</td>
<td>2.80</td>
<td>0.7</td>
<td>0.2</td>
<td>1.1</td>
<td>44.00</td>
<td>98</td>
</tr>
<tr>
<td>P5, 20-40</td>
<td>5.31</td>
<td>4.71</td>
<td>6.86</td>
<td>0.34</td>
<td>9.57</td>
<td>2.00</td>
<td>0.5</td>
<td>0.2</td>
<td>1.1</td>
<td>39.71</td>
<td>98</td>
</tr>
<tr>
<td>P5, 40-60</td>
<td>5.20</td>
<td>4.80</td>
<td>5.14</td>
<td>0.26</td>
<td>9.84</td>
<td>2.30</td>
<td>0.6</td>
<td>0.1</td>
<td>0.9</td>
<td>39.63</td>
<td>98</td>
</tr>
</tbody>
</table>

P1 ... Pn points; OM, organic matter; NT, total nitrogen; C.E.C, cation exchange capacity; SB, base saturation; P, phosphorus.

2007). This acidity alters soil processes, increasing the acid hydrolysis, leaching of base cations, fungal activity and reducing nitrification, thus affecting agricultural and forestry production (Lilienfein et al., 2000). Casierra
and Aguilar (2007) reports that in mineral acid soils with pH below 5.5, a large proportion of the clay exchange sites are taken up with aluminum, where it replaces other cations such as Mg²⁺ and Ca²⁺, and simultaneously adsorbs phosphates. The ΔpH value, defined as the difference between pH H₂O and pH KCl, is generally used as a qualitative indicator of the presence of variable load minerals. In this study, the values of difference are positive, suggesting the presence of negatively charged colloids (Tan, 1993). In relation to the exchangeable bases, calcium, magnesium and potassium have low values, which can be considered as representing a critical level. The base saturation percentage is less than 53%, with the trend decreasing with soil depth, indicating high rates of leaching and nutrient loss due to high rainfall and the physiographic features present in the study area. Similar results were observed by Bautista et al. (2005) in the cloud forests of El Rincón, in Oaxaca, Mexico.

The soils being studied are characterized by high contents of organic waste, which can be characterized as an O horizon. This ranged from 3.5 to 11 cm in depth, considering that the production of biomass in the Fgm forest incorporates 49.14 tonnes per hectare of leaf litter, representing 9.82 tons per hectare of soil organic carbon as a storage source for the soil fauna. The high content of OM suggests an adequate supply of N in the soil; however, these organic products form highly stable organo-mineral complexes with Fe, Al and Mn (Johnson, 2002).

Soils with high OM content may have both higher CEC and a lower pH, because the OM contains a large amount of carboxyl groups (R-COOH), which results in a high density of ionized sites, the release of H⁺, and consequently acidic pH (Johnson, 2002).

### Total oxides in soil under Fgm

Table 2 shows the total content of oxides, with SiO₂ values. It can be observed that the oxides are mafic materials. It can also be observed the scarcity of the oxides Mg, Ca, Na, and K and the enrichment of Al₂O₃, which represents approximately 70% of the total of other oxides. The presence of Fe sesquioxides increased relative to soil depth with the exception of P₂; while the P, Ti and Mn oxides exhibit variable behavior, in parts decreased with depth and, in others, increased.

The environmental conditions, in which soils developed, such as mild climate and good drainage, have favored the alteration of primary minerals. From the geochemical point of view, Aristizábal et al. (2009) report that these chemical changes reflect the formation of secondary clay minerals, predominantly halloysite and kaolin. With the reduction of soil pH, the destruction of

<table>
<thead>
<tr>
<th></th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>46.5</td>
<td>42.4</td>
<td>43.3</td>
<td>41.7</td>
<td>41.7</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.56</td>
<td>2.38</td>
<td>2.23</td>
<td>1.46</td>
<td>1.31</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>23.0</td>
<td>25.6</td>
<td>26.5</td>
<td>21.6</td>
<td>25.03</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>9.11</td>
<td>13.5</td>
<td>13.4</td>
<td>13.5</td>
<td>12.57</td>
</tr>
<tr>
<td>MnO</td>
<td>0.25</td>
<td>0.42</td>
<td>0.23</td>
<td>0.23</td>
<td>0.14</td>
</tr>
<tr>
<td>MgO</td>
<td>1.03</td>
<td>0.55</td>
<td>1.07</td>
<td>0.96</td>
<td>0.65</td>
</tr>
<tr>
<td>CaO</td>
<td>1.26</td>
<td>0.89</td>
<td>0.88</td>
<td>0.41</td>
<td>0.72</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.34</td>
<td>0.29</td>
<td>0.63</td>
<td>1.00</td>
<td>1.40</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.21</td>
<td>0.35</td>
<td>0.60</td>
<td>0.79</td>
<td>0.34</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.10</td>
<td>0.36</td>
<td>0.25</td>
<td>0.15</td>
<td>0.18</td>
</tr>
<tr>
<td>PXC</td>
<td>182</td>
<td>132</td>
<td>107</td>
<td>18.1</td>
<td>18.69</td>
</tr>
<tr>
<td>Total</td>
<td>101</td>
<td>100</td>
<td>100</td>
<td>102.7</td>
<td>101</td>
</tr>
</tbody>
</table>

P1 … Pn points; PXC: loss on calcination.
clay minerals and other silicates occurs, as well as the solubilization of aluminum oxides, which leads to irreversible soil degradation. Aluminum occurs in cases, such as Al^{3+} (Casierra and Aguilar, 2007). The loss values due to calcination are high (Table 2) due to the presence of organic compounds, with this increase being greater than higher percentages of OM (Table 1). The molar ratios SiO_2/Al_2O_3 and SiO_2/Fe_2O_3 (not reported) at all points showed moderately low values, representing a high level of temperature.

**Infrared spectra**

The interpretation of the spectra took into account the researches of Besoain et al. (2000) and Sagar and Singh (2007), although with different intensities. Figure 2 corresponds to the IR spectrum of the organic layer, showing a broad band at 3700 and 3100 cm\(^{-1}\), attributable to the OH bond tension vibration. At 2920 and 2850 cm\(^{-1}\), two peaks appear that correspond to CH valence vibrations (produced mainly in the humic type substances). At 1600 and 1700 cm\(^{-1}\), a band appears due to the CO vibration of carboxyl groups and aliphatic ketones, while the central spectrum at 1636 cm\(^{-1}\) corresponds to the IR spectrum of the organic layer, the vibrations of the stretching of the Si-O tetrahedra appear (Figure 3) with a peak of 1640 cm\(^{-1}\), indicating the presence of molecular water or crystallization. Besides the (OH)\(^{-}\) groups, the main absorption bands due to silicon appear between 1100 and 1000 cm\(^{-1}\), indicating the presence of silicates (Si-O), with the vibrations corresponding to aluminum in octahedral coordination with a range of 800-950 cm\(^{-1}\). Weak bands are observed between 2900-2800 cm\(^{-1}\), with the CH bond probably induced by residual OM

![Figure 2. Infrared spectrum (Item 2, organic layer) of Fagus grandifolia subsp. mexicana forest.](image-url)
adsorbed by the material (Janaki and Velrej, 2011).

**Conclusion**

Based on the results obtained in this study, it can be said that the potential fertility of the soil studied here is low, mainly due to the scarcity of exchangeable base cations, acidic pH (<5.3), and probable toxicity problems for the content of exchangeable aluminum. However, the Fgm has adapted to these soil conditions to develop physiological mechanisms. This is possibly due to the OM high content in the soil where most of Al ions form stable complexes (aluminum-organic), which reduce the phytotoxicity of the element. Furthermore, some Al ions are able to incorporate themselves into intermediary layers of the expanded minerals of clays, in the tolerance of Fgm to the element.

Fgm forests are in danger, if the degradation of this natural resource continue, not only the ecosystems of the different species will disappear, but also human life will be at risk.

**REFERENCES**


Cite this article as:

Submit your manuscript at http://www.academiapublishing.org/ajsr