Soil Quality in Terms of Physical-Chemical-Metal Properties for Barely (Hordeum vulgare) Production in the State of Hidalgo, Mexico

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Abstract: Soil chemical data is necessary for predicting the crops’ potential yield. The objective was to characterize the soil of the municipalities of Almoloya, Apan and Emiliano Zapata in the State of Hidalgo, Mexico in terms of physical-chemical-metal parameters. The following variables were determined in the soil samples; pH, electrical conductivity (EC), redox potential (Eh), zeta potential (ζ), soil moisture, ash content, organic matter (OM), inorganic nitrogen (IN), organic nitrogen (ON), total nitrogen (TN), soil texture, cation exchange capacity (CEC) and the following metals Ca, Mg, K, Fe, Ni, Cd, Pb and Mn. The pH varied from a range of 6.30 in Almoloya’s soil to 6.80 in Apan’s soil. The EC was higher in Emiliano Zapata’s soil with a value of 0.35 dS m⁻¹. The Eh was in a range of -19.84 mV observed in Almoloya soil through -29.90 mV in Apan soil. The ζ was -18.73 mV in Emiliano Zapata’s soil and -25.24 in Almoloya’s soil. The Na, K and Mg concentrations were highest in Apan soils with 30.95, 17.34 and 6.27 mg kg⁻¹ respectively, while Ca (69.27 mg kg⁻¹), Pb (1.04 mg kg⁻¹) and Ni (0.42 mg kg⁻¹) concentrations were highest in Emiliano Zapata’s soil.

Keywords: Metals %Mexico%Redox potential and zeta potential

INTRODUCTION

A soil’s characterization is fundamental to know its quality and potential to produce agricultural products. For instance, the barley (Hordeum vulgare) production is incremented in fertile soil; but, high production and productivity might be obtained in lightly soils (no depth) with clay accumulation and gravel particles. In addition, it is well documented that barley is a salt tolerance crop [1, 2, 3]. In fact, the barley crop is considered the most salt tolerance of the known cereals [4] estimating that this crop may tolerate levels of 8 dSm⁻¹ in the soil’s saturation extract without yield reduction [3]. Mano and Takeda [5] identified some barley genotypes that may germinate in levels of 40 dSm⁻¹ which is a salt concentration similar to that found in sea water. For the particular case of barley production, the compacted soil may damage seed germination and reduce growing of young plants. In general, the malting barley production is carried out in calcareous soils and low levels of nitrogen. High levels of nitrogen may increase the plants’ beat down and induce high levels of nitrogen in grain which is a negative parameter to the industry.

The heavy metals are also present in the soil as a natural component or due to anthropogenic activities. The may be present as free ions, as metallic salts, as insoluble compounds or partially solubilizable as oxides, carbonates or hydroxides [6]. These elements may be captured and retained in the soil particles or may be mobilized in the soil solution through biological and chemical mechanisms [7]. Heavy metals are redistributed in the different components of the solid face of soil; this redistribution, is characterized for an initial rapid retention of the elements and then a slow reaction is presented that will depends of the metal, soil properties and other variables [8]. Once the heavy metal content in soil is higher than the maximum permitted levels they will produce immediate negative effects as plant’s growth inhibition [9], a functional
disturbance in other components [10, 11] as well as a reduction in microorganism populations [12, 13]; but, most importantly, a potential human health risk [14]. The heavy metal's toxicity depends on metal concentration as well as to the mobility and reactivity of other ecosystem components [15]. It is well documented that the heavy metals in soils are contributing to the environmental contamination [16]. Once in soil, the availability of these metals is a function of some parameters like pH, clay content, organic matter content, cation exchange capacity and other properties that are unique to manage contamination [17].

Even though there is much information concerning heavy metals in soil and its characterization in different soil types, there is no information for soils that traditionally have been utilized to barley production.

The objective of this research was to categorize some soils in terms of physical-chemical-metals that are presently dedicated to barley production in three municipalities of the state of Hidalgo in Mexico. These results will be share to the Mexican’s barley producers to increment productivity of this crop in Mexico.

MATERIALS AND METHODS

The study was carried out in 2009 in three municipalities of the State of Hidalgo, Mexico; Almoloya, Apan and Emiliano Zapata. These areas are located in the central part of Mexico and traditionally, are well known producers of barley, which grain is further utilized in the malting industry. In fact, the State of Hidalgo is considered the largest producer of barley in Mexico with about 120,000 ha in average during the period of 1997-2007 [18]. Three field areas were selected in Almoloya (P1, P2 and P3), two field areas in Apan (P4 and P5) and two field areas in Emiliano Zapata (P6 and P7). In Figure 1 are

Fig. 1: Map of the central part of Mexico, showing the soil sample locations of the municipalities of Almoloya (P1, P2 and P3), Apan (P4 and P5) and Emiliano Zapata (P6 and P7) in Mexico.
clearly showed these areas. In each field, 13 soil samples were randomly obtained that were then shaken to have a composite sample. As a result, three composite samples were obtained for Almoloya soil, two for Apan and three for Emiliano Zapata soil. The 13 soil samples were obtained according to the following formula suggested by Munch and Angeles [19] and Tamayo and Tamayo [20].

Once collected, the soil samples were properly dried, grounded and passed through a 0.3555 mm sieve to remove rocks, roots, insects and any other larger particles. In the saturation extract and according to the Mexican Norm [21] were detected the following parameters; pH, electrical conductivity (EC), redox potential (Eh) and zeta potential (\(\zeta\)). The pH was measured using a standard glass electrode while the EC was calculated in a soil-water proportion 1:1 [22]. The Eh was detected potentiometrically while the zeta potential was measured in a zetamizer device 3000HSA of Malvern in glass cells of 1 cm. Lastly, the size and distribution of colloidal particles were obtained using an analyzer of laser diffraction LS13-320 Beckman Coulter [23].

In addition, water content, ashes, organic matter (OM), inorganic nitrogen (IN), total nitrogen (TN), soil texture (Bouyoucous method) and cation exchange capacity (CEC) were detected in the soil samples according to the Mexican norm [21] along with the following metals; Ca, Mg, K, Fe, Ni, Cd, Pb and Mn. The digestion of soil samples to detect metals was accomplished using a microwave technique with soil particles lesser than 100 Fm. An amount of 0.2 g of soil sample was collected and 5 ml of concentrated nitric acids was added. As a first step, the samples were warmed to increase the pressure to 300 psi for 10 min. Then the pressure was kept constant for 10 min in potency of 1200 W and finally, 5 min cooled. The samples were then properly filtered and afforded to 50 ml with deionizer water. The metal analysis was performed in a spectrophotometer of atomic absorption Perkin Elmer, model.

**RESULTS AND DISCUSSION**

Table 1: Mean values of some parameters in three types of soils in Hidalgo, Mexico.

<table>
<thead>
<tr>
<th>Municipality</th>
<th>pH</th>
<th>EC (dS m(^{-1}))</th>
<th>Eh (mV)</th>
<th>((\zeta)) (mV)</th>
<th>Soil Moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almoloya</td>
<td>6.30</td>
<td>0.24 (0.015)</td>
<td>-19.84 (1.707)</td>
<td>-25.24 (0.763)</td>
<td>8.20 (0.191)</td>
</tr>
<tr>
<td>Apan</td>
<td>6.80</td>
<td>0.29 (0.017)</td>
<td>-29.99 (2.646)</td>
<td>-20.99 (0.638)</td>
<td>10.20 (0.124)</td>
</tr>
<tr>
<td>E. Zapata</td>
<td>6.76</td>
<td>0.35 (0.029)</td>
<td>-28.59 (2.111)</td>
<td>-18.73 (0.514)</td>
<td>6.95 (0.173)</td>
</tr>
</tbody>
</table>

Numbers in parenthesis is the standard deviation.
Fig. 2: Correlation among mean values of pH with mean values of Eh

Fig. 3: Correlation among mean values of pH with mean values of (|f1|), salt (salinity) content [40, 41]. Saline soils are associated with arid and semi-arid environments where the evaporation process is higher than precipitation.

Fig. 4: Zeta Potential (\(\zeta\)) variations at different pH values in the saturation extract. Notoriously, the Apan and Emiliano Zapata soils have a certain instability in the colloidal fractions at values close to neutrality (pH=7.5). Traditionally, these results may be explained by higher salt (salinity) content [40, 41]. Saline soils are associated with arid and semi-arid environments where the evaporation process is higher than the precipitation.

Table 1 shows the levels of EC in the soils tested. It should be noted that this parameter varied in a range of 0.24 dSm\(^{-1}\) in the Almoloya soil to 0.35 dSm\(^{-1}\) in the Emiliano Zapata soil. These results are identifying both soils as non-saline [21]. The saline soils could be present due to the parent material of the sedimentary rocks [42]. Figure 5 shows the correlation between pH variations and EC levels in the soils tested. Table 1 also shows the soil moisture content in the soils tested. It can be observed that moisture content was moderate or low (lower than 10%) which corresponds with the soil’s low clay content (< 60%); and consequently, the soil’s capacity to retain water is low. Figure 6 clearly shows that there is no correlation between soil moisture and the saturation extract of pH. This fact may explain a low level of organic matter associated to low clay content; so therefore, low humic and fluvic acids in soils would be expected.
Table 2: Mean values of some parameters in three types of soils in Hidalgo, Mexico

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Soil textural class</th>
<th>OM % and classification</th>
<th>OM% Dichromate</th>
<th>OM% Permanganate</th>
<th>CEC cmol kg^{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almoloya</td>
<td>clay</td>
<td>1.81 (0.09) Medium</td>
<td>6.34 (0.21)</td>
<td>1.81 (0.09)</td>
<td>10.53 (1.03)</td>
</tr>
<tr>
<td>Apan</td>
<td>clay</td>
<td>2.12 (0.11) Medium</td>
<td>8.36 (0.33)</td>
<td>2.12 (0.11)</td>
<td>13.42 (1.09)</td>
</tr>
<tr>
<td>E. Zapata</td>
<td>Sandy loam</td>
<td>1.68 (0.09) Low</td>
<td>4.97 (0.20)</td>
<td>1.68 (0.09)</td>
<td>6.85 (0.57)</td>
</tr>
</tbody>
</table>

Table 3: Mean values of metals (mg kg^{-1}) in three soils of Hidalgo, Mexico

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Na</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Pb</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almoloya</td>
<td>27.19 (0.85)</td>
<td>15.44 (0.83)</td>
<td>46.77 (0.32)</td>
<td>4.79 (0.06)</td>
<td>0.89 (0.02)</td>
<td>0.24 (0.01)</td>
</tr>
<tr>
<td>Apan</td>
<td>30.95 (0.61)</td>
<td>17.34 (0.38)</td>
<td>34.54 (0.91)</td>
<td>6.27 (0.18)</td>
<td>0.63 (0.07)</td>
<td>0.25 (0.01)</td>
</tr>
<tr>
<td>E. Zapata</td>
<td>26.55 (0.71)</td>
<td>1.28 (0.07)</td>
<td>69.27 (1.82)</td>
<td>3.68 (0.27)</td>
<td>1.04 (0.09)</td>
<td>0.42 (0.01)</td>
</tr>
</tbody>
</table>

Fig. 7: Correlation among organic matter (OM) content and cation exchange capacity (CEC) in three soils

The textural classes of the soils under study were classified as clay for Almoloya and Apan soils and sandy loam for the Emiliano Zapata soil (Table 2). The OM content was lower in the Emiliano Zapata soil with 4.97% using dichromate and 1.68% using potassium permanganate while highest levels were noted in the Apan soils (Table 2). It is clear that the Apan soil had high levels of OM, higher levels of clay content and higher moisture content. Moreover, it is important to point out that the index permanganate/dichromate (Table 2) varied in a range of 0.25 in the Apan soil to 0.34 in the Emiliano Zapata soil. It is generally accepted that the permanganate method measures the OM available in the clay extracts [43]. Hence, the results presented here may assume that about 25-34% corresponds to available OM. Furthermore, there is a strong relationship between OM content and the CEC. For this reason, it was not surprising that the Apan soil presented the higher CEC with levels of 13.42 cmol kg^{-1}(Table 2). One must remember that the Apan soil showed the higher clay content. Pierzynski et al. [44] hypothesized that any clay soil that has the natural capacity of better cation exchange capacity; so, that might explain the fact that the higher clay capacity will have a soil CEC higher in correspondence with alkaline pH levels. This correlation is shown in Figure 7. Our CEC’s results agree with the information reported by Stehouwer [45] who mentioned that most soils from temperate areas fall in a range of 8-25 cmol kg^{-1}.

The metal concentration of soils found in this study is presented in Table 3. The Emiliano Zapata soil had the highest Ca concentration with 69.27 mg kg^{-1} which may be explained for the application of liming materials in the production of local agricultural products. Table 3 also shows that the Emiliano Zapata soil presented the lower level of K, Na and Mg; nevertheless, it had the highest concentration of Pb (1.04 mg kg^{-1}) and Ni (0.42 mg kg^{-1}). The lower CEC of the Emiliano Zapata soil may be explained by the low K concentration and the observable disproportion of Ca and Mg concentrations. It can be noted that the relationship Na'/K' of 20.83 which is the higher value corresponds to the lowest CEC level.
Fig. 8: Correspondence of the values of relations between metals and CEC for the different soils in study

Fig. 9: Average concentrations of metals in soils and his correspondence with the percentage contents of ashes (Figure. 8). This highest value of 20.82 is calculated by the low K⁺ levels in the Emiliano Zapata soil and the relationship of Ca²⁺/ Mg²⁺ due to high levels of Ca²⁺. Undoubtedly, this is correlated with the management of agricultural soils, different fertilization practices and the liming materials applied. All these practices are causing the continuous deterioration of the soil and consequently are affecting the yield and quality of the malting barley. Other studies have shown that the other important factor is related to the presence of salts especially of calcium, magnesium and sodium in higher horizons of the soil [46] which affect the root’s environments [47].

The ash amount was higher in the Emiliano Zapata soil with 75.04% when compared to 62.55% in the Apan and 67.00% in the Almoloya soils. These results are in accordance with the textural class (sandy loam) of each particular soil. We must clarify that we take care of the proportion of metals in soil (mg kg⁻¹) with the ash percentages (Figure 9). This is important because the ash content is associated with metallic oxides after the OM is properly combusted and the decomposition of carbonates and bicarbonates.

CONCLUSIONS

According to the results, the following conclusions may be given. The pH values found in this study are characteristic and favorable to barley production in the three municipalities under study. In general, the soils have acceptable nutrient balance; however, the Emiliano Zapata’s soil may be higher in Ca and low in K and so the barley productivity may drop. The soils may be classified as intermediate to high reductors according to their values of Eh. A low OM level in these soils is causing low moisture retention and as well as low CEC. The soils tested have no salinity problems.

REFERENCES


