Physicochemical characterization of agricultural soils under a traditional system in the Mezquital Valley, Hidalgo

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ABSTRACT
The study examines alkaline and sodic soils, characterized by a pH exceeding 7.5 and elevated exchangeable sodium, indicative of deficiencies in nitrogen, manganese, iron, zinc, and copper in crops. Its objective is to characterize agricultural soils under traditional and conventional systems using physical and chemical parameters to advocate for regenerative agriculture. Sampling and analysis adhere to Nom-021-RECNAT-2000 standards. Predominantly, the soils exhibit clay loam and sandy loam textures across Tula de Allende, Tezontepec de Aldama, Francisco I. Madero, and San Salvador municipalities. Organic matter percentages vary, classified as very high (Tula de Allende and San Salvador), high (Tezontepec de Aldama, Mixquiahuala de Juárez, and Francisco I. Madero), and low (Santiago de Anaya). The pH ranges from moderately alcaline to highly alkaline. Cation exchange capacity in irrigation zones varies from very high to high, and medium for Tezontepec and Santiago de Anaya, which rely on rainfed irrigation. Elevated nitrate (NO$_3^-$), phosphorus (H$_2$PO$_4^-$), and potassium (K$^+$) concentrations are noted across different municipalities. These findings prompt reconsideration of traditional tillage practices that exacerbate sodicity in agricultural soil.

Keywords: Alkalinity, Macroelements, Salinity, Physicochemical Variables.
1 INTRODUCTION

The Mezquital Valley, Hidalgo, is made up of 27 municipalities; it is characterized by a semi-desert climate, with an average temperature of 18 °C and low precipitation (524 millimeters per year); the vegetation is mainly xerophytic (Moreno, 2006). The region is classified into three subregions: the northern and northeastern subregion, center and south, and central subregion with different soil characteristics, which include lithosols, calcareous feozems, feozems with a large contribution of carbonates, regosols, habic feozems, lithosols and soils characterized by a surface layer rich in humus and organic matter (Aguilar et al., 2019). The Mezquital Valley stands out as an agricultural region, its main economic source is agriculture, which accounts for 59 % of the state’s total production (Moreno, 2006). However, for one hundred and twenty-three years this region has been using wastewater from the Metropolitan Zone of the Valley of Mexico as a response to the serious flooding problems suffered by Mexico City during the “Porfiriato”. From this, there was a growth in agriculture in the Mezquital Valley (García, 2019). In this way, the water resource transformed a space suitable for the development of a diversity of crops in the state of Hidalgo. Currently, part of this wastewater is distributed in the main irrigation districts of the state corresponding to District 003 of Tula, 100 of Alfajayucan and 112 of Ajacuba, in which approximately 80,000 h are irrigated. The traditional agricultural production system in the Valley and Alto Mezquital Hidalgo are characterized by tillage practices that involve soil movement with various agricultural implements. In order to fracture the hardened or impermeable layers, as a result of excessive irrigation and/or rainfall, and thus "improve" the soil structure and facilitate the movement of water and air. This system is also characterized by the establishment of monocultures, removal or burning of agricultural residues and dependence on agro-inputs (Prieto et al., 2005; Santiesteban et al., 2007; Rodríguez et al., 2017). The main crops where rolled irrigation is provided are alfalfa, corn, oats, barley, beans, turnip, cauliflower, zucchini, green chili, and tomato (Pérez et al., 2019). However, the wastewater that reaches the Mezquital Valley has a high load of organic and microbiological material and concentrations of contaminating compounds such as: detergents, factory waste, and some metals (Prieto et al., 2005). Therefore, this research was carried out with the purpose of characterizing agricultural soils under a traditional or conventional system, using physical and chemical parameters in order to promote the use of regenerative agriculture.
2 THEORETICAL FRAMEWORK

Soil is the fundamental part of natural ecosystems, serving as substrate, anchorage and nutrition for plants. However, fertility alterations often restrict or prevent optimal yields. The Mezquital Valley has several municipalities with salinity and alkalinity problems (Cornejo O, 2012).

Soil salinity can occur due to natural effects; however, the main cause is inadequate irrigation management, lack of soil drainage, indiscriminate use of agro-inputs, as well as inadequate application of amendments and other animal wastes (Delgado G, 2022). Soil salinity is characterized by high concentrations of sodium (Na\(^+\)), calcium (Ca\(^{2+}\)), magnesium (Mg\(^{2+}\)) and chloride (Cl\(^-\)), sulfate (SO\(_4^{2-}\)), bicarbonate (NaHCO\(_3\)) and carbonate (CO\(_3^{2-}\)) anions (FAO, 2021).

These elements and compounds cause toxicity in plants such as: limitation of germination percentage, limiting vegetative development, osmotic stress, plant chlorosis, wilting and possible death of crops that are not tolerant to salinity. It also produces a series of modifications in the chemical properties of the soil, such as pH variations and low biodiversity. Salinity causes antagonisms between nitrate-chloride, potassium-sodium, calcium-sodium (Ortega-Escobar et al., 2023).

Salinity brings with it other problems such as: limited absorption of nutrients, reduced translocation and recycling of ions in the plant (Dufour, 2021). On the other hand, alkaline soils arise due to their own edaphology, due to the decomposition of minerals rich in soluble salts or because they are soils in arid areas with low rainfall. However, another important factor is human intervention due to inadequate agricultural management of the plots (FERTILAB, 2020).

Alkaline soils are characterized by having a pH above 7.5 with the presence of bicarbonates (NaHCO\(_3\)). The disadvantage of these soils is that they also have a high content of exchangeable sodium; as its concentration increases it begins to replace other cations, which reflects a deficiency of manganese (Mn\(^{2+}\)), iron (Fe\(^{2+}\)), zinc (Zn\(^+\)), copper (Cu\(^{2+}\)) in established crops (Cremona; Enriquez, 2020). It is worth mentioning that, alkalinity is a problem that threatens the quality of agricultural soils, being a limiting factor in food production because crops lose their yield potential and nutritional quality (Herrera, 2024).

In the face of salinity and alkalinity problems, the evaluation of soil fertility is key to making agricultural amendments and subsequently dosing fertilizers in order to balance the physicochemical characteristics of the soil.

3 METHODOLOGY

The study was conducted within the Valley and Alto Mezquital area, Hidalgo, Mexico. The study areas are located in five deferred municipalities (Figure 1) Tula de Allende at coordinates N 20°06’59.3"
and W 99°19'36.2'', Tezontepec de Aldama at coordinates N 20°07'00.3" and W 99°13'08.8'', Mixquiahuala de Juárez at coordinates N 20°12'35.6" and W 99°13'27.2", Francisco I. Madero at coordinates N 20°13'46.9" and W 99°05'21.23", San Salvador at coordinates N 20°16'57.6" and W 99°00'19.8" and in the municipality of Santiago de Anaya at coordinates N 20°24'51.4" and W 99°04'27.3". It should be noted that sampling was carried out in autumn-winter at the end of the spring-summer crop cycle. In the sampling areas, the traditional or conventional tillage system is used, where stubble is commonly removed from the plots, subsoiling and harrowing practices are implemented at a depth of 0-30 cm; followed by furrowing (0.75 cm) sowing. The samples were collected before the spring-summer crop cycle from completely randomized plots in municipalities belonging to the valley and Alto Mezquital where 30 soil subsamples were collected at a depth of 0-30 cm, using a stainless-steel auger with the AS-01 method based on NOM-021-RECNAT-2000.

Physicochemical determinations of the soil. The Bouyoucos hydrometer method was used to determine and evaluate texture (Medina et al., 2007), pH and electrical conductivity by digital potentiometer (HANNA; HI-2213), organic matter by the Walkley and Black method (1934), cation exchange capacity by the AS-13 method (NOM-021-RECNAT-2000), and the determination of nutrients: nitrates, phosphorus and potassium in the soil, using the HI83225 Grow master® photometer. The data obtained were analyzed by a randomized complete block experimental design; using R-Core Team version 2022 and tested for significance ($p \leq 0.05$).
4 RESULTS AND DISCUSSIONS

Parameter as a result of the flood irrigation system and the proximity to industrial areas of the Tula region, which lead to physical degradation, as stated by (Oviedo et al., 2012). In Tezontepec de Aldama and Mixquiahuala de Juárez, clay loam type soils were determined that are appropriate for the development of vegetables, cotton, legumes and grasses (Reyes et al., 2023).

Table 1. Physical and chemical properties of soil under traditional tillage at six sites in the Mezquital Valley. Different literals between columns are significantly different (Tukey, p ≤ 0.05). Mo: organic matter, CE: electrical conductivity and CIC: cation exchange capacity.

<table>
<thead>
<tr>
<th>Municipalities</th>
<th>Textural class</th>
<th>% Mo</th>
<th>CE dS/m</th>
<th>CIC cmol+ Kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tula de Allende</td>
<td>loam</td>
<td>4.18±0.03</td>
<td>1.65± 0.42</td>
<td>28.6±0.20</td>
</tr>
<tr>
<td>Tezontepec de Aldama</td>
<td>Clayey loam</td>
<td>3.94±0.65</td>
<td>0.85±0.54</td>
<td>24.5±0.34</td>
</tr>
<tr>
<td>Mixquiahuala de Juárez</td>
<td>Clay loam</td>
<td>3.50±0.28</td>
<td>1.35±0.56</td>
<td>42.2±1.83</td>
</tr>
<tr>
<td>Francisco I. Madero</td>
<td>Clay</td>
<td>2.96±0.12</td>
<td>1.40±0.71</td>
<td>40.5±0.34</td>
</tr>
<tr>
<td>San Salvador</td>
<td>Loam</td>
<td>4.03±0.07</td>
<td>1.10±1.08</td>
<td>29.8±0.04</td>
</tr>
<tr>
<td>Santiago de Anaya</td>
<td>Sandy loam</td>
<td>1.59±0.46</td>
<td>1.01±0.19</td>
<td>24.7±0.62</td>
</tr>
</tbody>
</table>

Source: Own elaboration.

Physicochemical properties. Table 1 shows the textural class of the experimental soils, Tula de Allende reports a loamy texture, however, in previous studies textures of sandy clay loam to clay loam were reported; The above denotes a slight modification of this. In San Salvador the texture is loam, similar to previous studies in which it is reported that 75% of the soils in this municipality have the same textural class (Prieto et al., 1994). On the other hand, in Santiago of Anaya it presents a sandy loam texture. As a neighboring place and belonging to the municipality of Actopan, Chicavasco, also reports the same textural class (Delgado et al., 2022). The influence of soil texture affects soil structure, root development, aeration, drainage capacity, water storage, plasticity, and nutrient retention (Largaespada, 2015).

Table 1 shows significant difference (Tukey, p ≤ 0.05) in the percentage of organic matter for the different study areas. The municipality of Tula de Allende and San Salvador reported high organic matter content for non-volcanic soil. A previous study indicates that this parameter has increased in this area over the years as a result of the continuous use of wastewater (Prieto et al., 1994). Tezontepec de Aldama and Mixquiahuala de Juárez report a medium to high percentage for non-volcanic soils based on NOM-021-RECNAT-2000; similar to an investigation that positions Lagunilla and Mixquiahuala with values below 4 % (Prieto et al., 1994). Francisco I. Madero reports a medium organic matter content (Tukey, p ≤ 0.05). The excessive use of agro-inputs and the management of
crop residues are the main factors for the increase of this parameter (Delgado et al., 2022). Due to its low rainfall and xerophytic ecosystem, the municipality of Santiago de Anaya reports low organic matter content in non-volcanic soils based on NOM-021-RECNAT-2000.

The values of organic matter modify the availability of some elements, and is a parameter that harms or benefits biological diversity such as the presence of nitrogen-fixing microorganisms to generate the availability of this element (Julca et al., 2006). Another parameter evaluated was pH in which, significant differences are reported (Tukey, $p \leq 0.05$); Tula de Allende reports 8.23, Tezontepec de Aldama 7.86, Mixquiahuala de Juárez 8.11, Francisco I. Madero 8.02, for San Salvador with pH of 8.23 is reported and Santiago de Anaya 9.07. Previous studies in similar and neighboring areas refer to soils being classified as having moderate to high alkaline (Rodríguez et al., 2017). Tula de Allende and San Salvador have higher organic matter content and report the same pH and texture. Santiago de Anaya has high alkaline soil, related to the low percentage of organic matter. It is worth mentioning that the pH is attributed to the geology of the study area (Aguilar et al., 2019). Soil pH is important because the absorption and availability of micronutrients and macronutrients for plants depends on it, as well as soil microbiological activity and chemical processes that occur from this parameter (Castillo et al., 2009). Significant differences (Tukey, $p \leq 0.05$) are reported in electrical conductivity (See Table 1). Tula de Allende, Francisco I. Madero, Santiago de Anaya, Mixquiahuala de Juárez and San Salvador report very little saline soils based on NOM-021-RECNAT-2000. It is worth mentioning that research reports negligible values to salinity in similar or neighboring areas (Rodríguez et al., 2017; Prieto et al., 1994). Tezontepec de Aldama reports negligible effects to salinity related to the aforementioned parameters. For Mixquiahuala de Juárez and Francisco I. Madero a very high cation exchange capacity (CIC) is reported; both municipalities show a significant difference (Tukey, $p \leq 0.05$) to the rest of the study sites (See Figure 2). It is worth mentioning that previous studies report a CIC $\geq 40$ cmol (+) kg$^{-1}$ in similar or neighboring areas (Prieto et al., 2005). San Salvador and Tula de Allende are in a high classification, and the municipalities of Tezontepec de Aldama and Santiago de Anaya are classified in a medium class. Cation exchange capacity (CIC) is an indirect parameter of the soil to exchange cations, and provides information on soil fertility (Castaño, 2022).

The exchangeable bases are the sum of more than 12 cmol (+) Kg$^{-1}$ of Ca$^{2+}$ and Mg$^{2+}$ indicates that soil fertility is high (Muñoz, 1978). Figure 1 shows that all the study sites are fertile and statistically different (Tukey, $p \leq 0.05$), however, the rainfed zone of Santiago de Anaya should be highlighted, where the lack of water has reduced the productivity of this zone (Prieto et al., 1994).
The municipality with the highest concentration of sodium (Na\(^+\)) is Mixquiahuala de Juárez (p ≤ 0.05). It is important to mention that these concentrations reduce the assimilation of K\(^+\), NO\(_3^-\), H\(_2\)PO\(_4^-\) causing a slow development of the root area and decreases crop yield due to osmotic stress (Lamz, 2013).

Exchangeable bases allow adsorption, association and exchange of nutrients. The concentration is related to the textural class and the amount of organic matter reported previously, (Perez et al., 2022).

The soil fertility is the NO\(_3^-\) in soil is considered an essential macronutrient because it is part of organic compounds, including growth hormones essential in plant metabolism, likewise it is essential for the formation of proteins, nucleic acids, chlorophylls and enzymes of the cytochrome group, indispensable for photosynthesis and respiration, and in several coenzymes, such as nicotianamine, adenine and dinucleotides (Antúnez et al., 2014).

Differences in NO\(_3^-\) concentrations were observed and were high for Tula de Allende. Previous studies show very high concentrations of 53.74 NO\(_3^-\) at a depth of 30 cm in nearby areas (Delgado et al., 2022). In Mixquiahuala de Juárez, Santiago de Anaya, Francisco I. Madero and San Salvador, there is a medium concentration; in contrast, the municipality of Tezontepec de Aldama has a low content (Juárez et al., 2020).

If NO\(_3^-\) deficiencies occur, plant vigor is reduced, producing chlorosis and low yields (Mixquititla et al., 2020).
Figure 2. Microelements concentrations in six municipalities of the Mezquital Valley, Hidalgo.

Phosphorus is an essential microelement for plant development because it is an important factor for the process of photosynthesis, and the mobility of other nutrients to the plant, inducing root development, enhancing flowering and fruit formation (Torres, 2016). It promotes plant metabolism, such as carbohydrate biosynthesis, lipid biosynthesis, chlorophyll synthesis, carotenoids, glycolysis and metabolism of organic acids, leading to fruit ripening and the production of viable seeds for subsequent generations (Torres, 2016). Significance is reported in all the municipalities evaluated (Tukey, $p \geq 0.05$) and the concentrations are in a very high range of available phosphorus ($\text{H}_2\text{PO}_4^-$) according to NOM-021-RECNAT-2000. It is worth mentioning that similar zones belonging to the Mezquital Valley present similar concentrations ($\geq 11 \text{ cmol+ Kg}^{-1}$) (Delgado et al., 2022).

Potassium ($\text{K}^+$) is an essential microelement for plant development, since its deficiency is manifested in the physical characteristics of plants due to the large quantities required by the plant. It is required four times more than phosphorus for the same need of nitrogen (Coronel, 2003). It should be noted that high levels of this element cause Mg$^{2+}$ and Ca$^{2+}$ deficiency, resulting in glassy stems, with stiff, dull leaves (Coronel, 2003). Optimum concentrations are reported above 800 mg kg$^{-1}$; while low concentrations are $< 150$ mg kg$^{-1}$ reported by Ibarra, 2023. The present work reports significant difference (Tukey, $p \leq 0.05$) and very high potassium ($\text{K}^+$) concentrations for the municipalities of Francisco I. Madero, Santiago de Anaya and San Salvador; however, high concentrations are reported for Tezontepec de Aldama, Tula de Allende and Mixquiahuala de Juárez (Kolmans, 1996).

5 CONCLUSION

The importance of this research in the Valley and Alto Mezquital Hidalgo, emphasizes good usage and agricultural management of irrigation, the proper use of fertilizers, green manures, tillage systems,
stubble management, crop rotation, among other variables that influence the physicochemical properties of agricultural soils to increase fertility and agricultural production. Finally, to motivate and encourage producers to modernize traditional agriculture in a sustainable manner.

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