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Soil Quality in Terms of Pyhsical-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 potencial (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 dSm^{-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 solubizables 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

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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

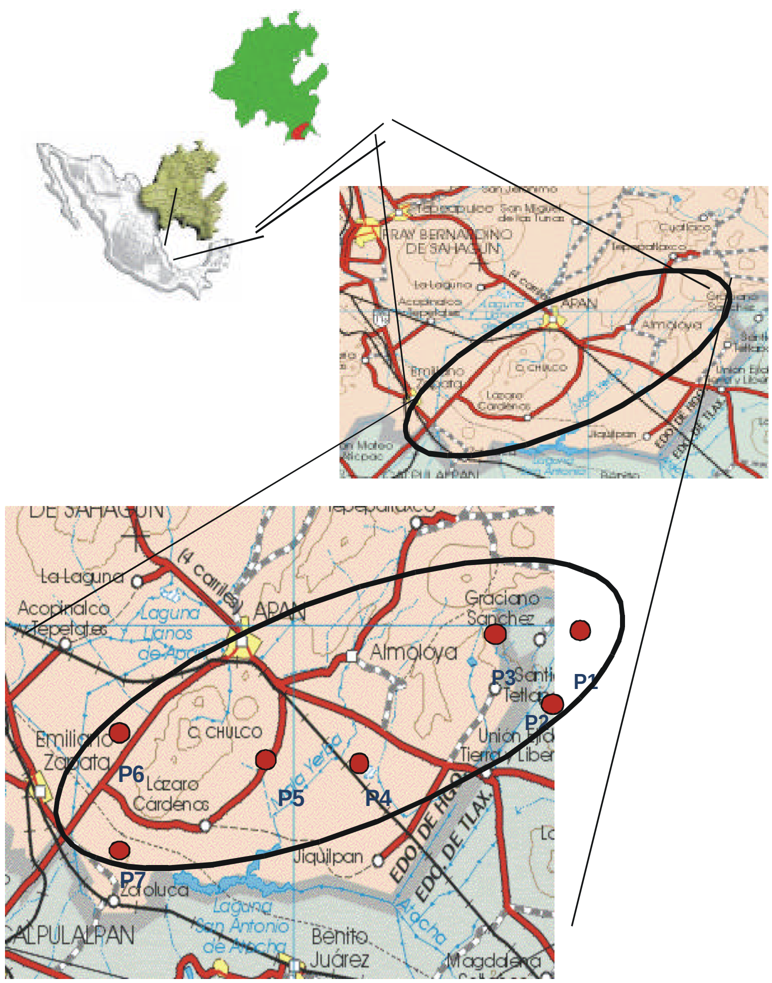


Fig. 1: Map of the central part of Mexico, showing the soil sample locations of the municipalities of Almoloya (P1, P2 and P3), Apan (P4 and P5) and Emiliano Zapata (P6 and P7) in Mexico.

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 (.). 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 potenciometrically while the zeta potential was measured in a zetasizer 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

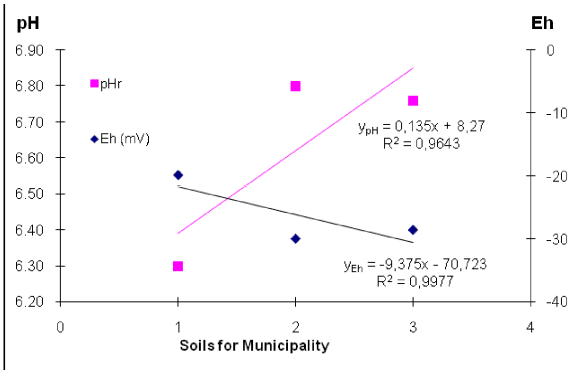
The pH varied from a range of 6.30 in Almoloya's soils to 6.80 in Apan's soil (Table 1); therefore, the Almoloya soil could be classified as slightly acidic while the Apan and the Emiliano Zapata soils could be classified as very slightly acidic [24, 21]. These pH values are typical in arid and semi-arid areas in water [25-27] as well as in soils [16, 28, 29] and are favorable for the production of the most comestible crops including the production of barley. It is well documented that extreme pH levels in soils may cause some nutrient precipitation and as such, would not be available for plant assimilation. For instance, low pH levels usually provoke toxic concentrations of Al and Mn [30, 31]. On the other hand, a pH of 8.5 and above indicates high levels of interchangeable sodium and the presence of some alkaline-terries metal carbonates [32]. It is important to point out that a soil's pH test is giving a measurement in the soil solution and it is not taking into account the reserve acidity or alkalinity in the soil.

The Eh varied from a range of -19.84 mV noted in the Almoloya soil through -29.99 mV observed in the Apan soil (Table 1). Eh values indicate that a given soil may be considered as an intermediate reductor. It is generally accepted that the Eh values define the oxidant-reduction character of any soil. Regarding (.) values, these varied from -18.73 mV in the Emiliano Zapata's soil to -25.24 mV in Almoloya's soil (Table 1) indicating that the colloidal suspensions of particles form low to moderate stables. It is important to point out that a level of < -30 mV indicates good colloidal stability in the liquid face of soils [33]. The results obtained and data gathered concerning soil classification are reported in these soils for the first time which is dedicated to the production of barley. Rubio *et al*. [34] described an interesting data using the zeta potential as a predicting variable for different heavy metals. Figure 2 shows the correlation level among the parameters pH and Eh while Figure 3 represents the correlation among the pH and (.). Knowledge of these parameters is important because they are a qualitative indicator of the biological activity, energy flush and nutrient cycle of any soil type. Hence, the aggregation of the soil's particles must be renovated throughout the biological processes [35 to 39]. Our results indicate low levels in the biological activity of the soils tested as well as low development in the nutrient cycle.

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

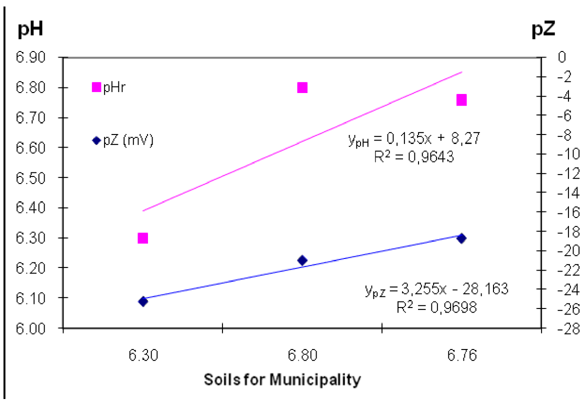
Municipality	pH	EC (dS mG^{1})	Eh (mV)	(.) (mV)	Soil Moisture (%)
Almoloya	6.30 (0.081)	0.24 (0.015)	-19.84 (1.707)	-25.24 (0.763)	8.20 (0.191)
Apan	6.80 (0.076)	0.29 (0.017)	-29.99 (2.646)	-20.99 (0.638)	10.20 (0.124)
E. Zapata	6.76 (0.038)	0.35 (0.029)	-28.59 (2.111)	-18.73 (0.514)	6.95 (0.173)

Numbers in parenthesis is the standard deviation



1. Almoloya; 2. Apan; 3; E. Zapata

Fig. 2: Correlation among mean values of pH with mean values of Eh



1. Almoloya (6.30); 2. Apan (6.80); 3; E. Zapata (6.76)

Fig. 3: Correlation among mean values of pH with mean values of (.|f1|)

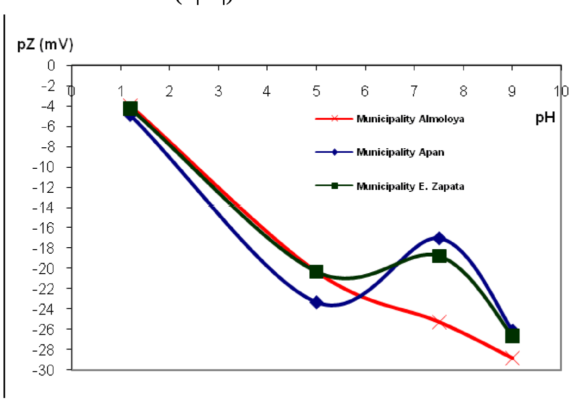


Fig. 4: Zeta Potential (.) variations at different levels of pH

Figure 4 shows the (.) 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

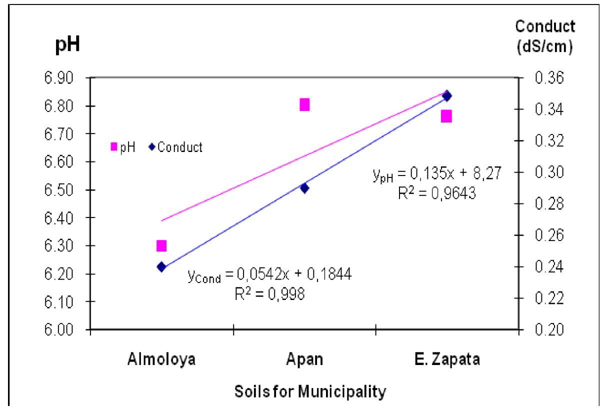


Fig. 5: Correlation level among pH and electrical conductivity (EC) in three soils.

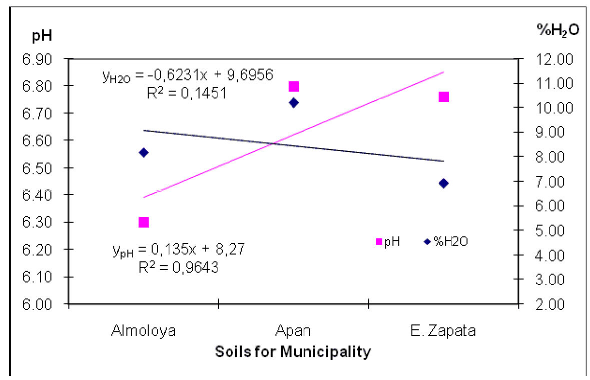


Fig. 6: Correlation level among pH and moisture content (%) in three soils

salt (salinity) content [40, 41]. Saline soils are associated with arid and semi-arid environments where the evaporation process is higher that 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 dSmG^{1} in the Almoyola soil to 0.35 dSmG^{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

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

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

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

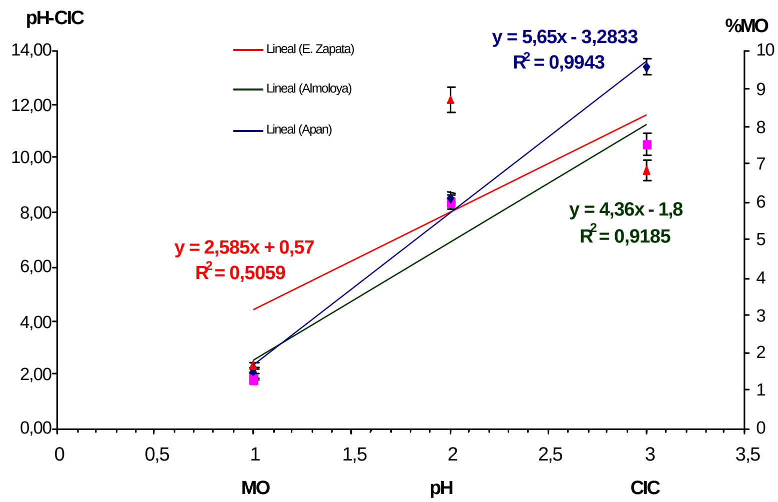


Fig. 7: Correlation among organic matter (OM) content and cation exchange capacity (CEC) in three soils

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

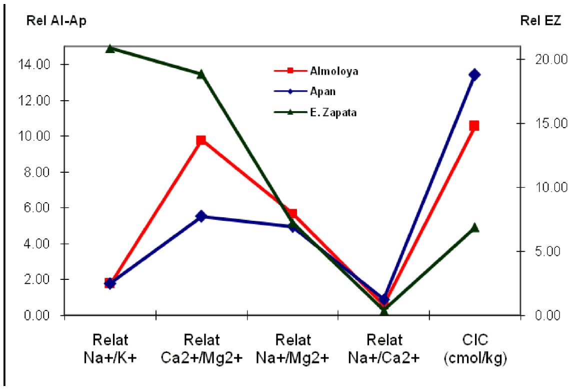


Fig. 8: Correspondence of the values of relations between metals and CEC for the different soils in study

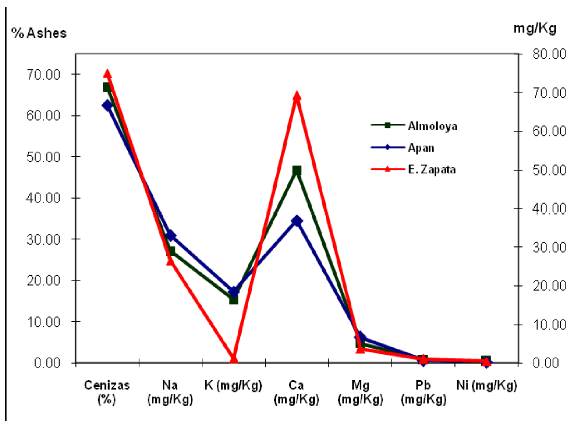


Fig. 9: Average concentrations of metals in soils and his correspondence with the percentage contents of ashes

(Figure. 8). This highest value of 20.82 is calculated by the low K^{+} levels in the Emiliano Zapata soil and the relationship of Ca^{2+}/ Mg^{2+} due to high levels of Ca^{2+}. 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 kgG^{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.

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