Correlation of moisture, pH and zeta potential (ζ) in sandy-clay-loam soils of the southern state of Hidalgo, Mexico

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Agricultural soils in savanna zones are very sensitive to compaction and crusting, which merits investigation because, with respect to rainfall, crusting occurs in them and no matter how thin the crusts become they prevent infiltration and root development. The aim of this study was to determine a general correlation between parameters of moisture, pH and zeta potential (ζ). The last two parameters were measured in the saturation extract of three soil samples dedicated to the cultivation and production of malting barley (Hordeum distichum), in order to develop a rapid and simple method of estimating the quality of this type of soil. The stability of the colloidal suspensions of soils, associated with colloids of organic matter, is diminished dramatically (increasing the ζ), to the extent that it decreases the biological crust cover (% CC) and clay content which subsequently decreases the textural composition and, therefore the soil moisture retention capacity. Land plots in the municipality of E. Zapata, demonstrated the worst textural conditions (lower % age of clay), lower moisture content, the lowest organic matter loading, higher bulk density and lower field capacity. All these aspects confirm that plots in the southern region of the State of Hidalgo, Mexico consist of more compacted soils which are less beneficial for growing barley.

Key words: *zeta potential, field capacity, textural class, moisture, soil quality.*

Introduction

Compaction causes physical and mechanical changes in the optimal relations that should exist between the plant and the soil's contents of nutrients, water and air. For the proper management and use of agricultural soils, it is necessary to know their moisture conditions in order to better use them without causing unfavorable structural agricultural changes. Agricultural soils in savanna zones are too sensitive to compaction and crusting. This merits investigation, because these soils are too sensitive to compaction and crusting, including rainfall crusting and consequently these thin soils have interrelated problems of surface sealing, soil compaction, poor drainage and impeded root development. The state of soil compaction is considered particularly important in restricting root growth, and as the soil moisture content and its interaction with the soil bulk density have a marked influence on the proportions of root elongation, typical soil moisture conditions should be used in assessing the status of soil compaction.

Compaction of sandy soils is the result of the arrangement of its particles. Kaolinitic clays are typically comprised of due to the arrangement of the layers which produce a low surface area, but always provide better soil aeration with much finer particles (Dertour et al., 1993). Fine-grained soils require more water in order to achieve optimum compaction than do coarse soils (Braunack et al., 1979) ie: the layers of smaller aggregates would be less compacted than the layers of larger aggregates under the same moisture content. According to McBride (1989) the predominant independent variables are density, moisture and stress functions with strong influences from the content of moisture, texture and organic matter.

Sandy loam soils are usually characterized by an average bulk density of 1800 kg.m^{-3} which generates a pore space of 30-32 % and an air volume of 10-12 % moisture. According to the literature, this physical condition is considered to be that of a compacted soil with a porosity which is inadequate for plants, whereas a clayey loam soil with a dry bulk density of 1550 kg.m^{-3}, which generates a pore space of 40-41 % and an air volume of 14 % with moisture content of 17 % is not considered to be a compacted product of its greater surface area, due to very small pores, and the water dominates aeriferos pore content which may not be a satisfactory condition for growth plant (Daniels, 1997).

On the one hand, soil composition is made up of pore volume (occupied by gas or liquid, or gas and liquid) and on the other hand, a different volume occupied by solid substances (Han et al., 2003). For the solid part, the soils skeletal structure dominates, constituted of large fractions which are chemically less active (ie. sand and silt) and is known as soil plasma. Then, there are smaller fractions which are mainly clay

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minerals, organic matter and oxides, and these are the components of the clay particle size fraction and have a high chemical activity. These constituents have certain characteristics that defined as colloids and their study is of vital importance, because of the role they play in soild (Sauve et al., 2000). They play a fundamental role in plant nutrition, due to their ability to absorb and to fix ions which are important roles in the dynamics of soil water, the formation acting on soil structure and, therefore determining other properties such as aeration, drainage, root penetration, among others. Soil can be viewed as a liquid colloidal, colloidal solution or hydrosoluble where water constitutes the dispersion medium and the dispersed phase is constituted by the soil plasma (Brady and Weil, 2008).

The negatively charged organic colloids is essentially dependent on the pH. Under strongly acidic conditions, hydrogen is strongly bonded to the functional groups and is not readily replaceable by other cations (Sumner and Noble, 2003; Prieto et al., 2011). The colloid, therefore exhibits a low negative charge and the cation adsorption capacity is also low. Before a pH increase, first the hydrogen of the carboxyl groups and then the enolic and phenolic groups ionize and are replaced by calcium, magnesium and other cations. Under alkaline conditions, the cation adsorption capacity by humus far exceeds that of most phyllosilicates (clay minerals) (Ferreras et al., 2007).

There are two sources of negative charges on soil colloids. Firstly, there are permanent loads resulting from isomorphous substitution of cations (Si, Al) with lower valence cations (Ca, Mg). This phenomenon is particularly important in phyllosilicate clay and partly explains the strong electronegativity of these clays. Permanent negative charges of soil loads are supplemented by or are dependent on variables of pH, organic matter, oxides of iron and aluminum and some mineral materials such as amorphous allophane (Rubio et al., 2010). In the case of organic matter, it was observed that the carboxyl groups are ionized and increase progressively and augment the negative charge as the pH is raised from very low values. The phenolic groups are ionized in a similar manner to reach above pH 7.

Since soils typically contain mixtures of mineral colloids, are both permanent and variable loads. In temperate-region soils dominated by clays, permanent negative charges are the most abundant. In highly weathered tropical soils, with predominantly clay, iron and aluminum oxides, and which are high in organic matter content, the negative charges are the more common variables, and they may be the only fully weathered tropical soils (Cantú et al., 2007).

The surface charges of the colloidal particles of soil which are in the solid-liquid interface cause the formation of an electric double layer that is located around the colloidal micelle. This double layer is composed mostly of ions with opposite to the charged surface and are electrostatically attracted to it. At the same time, these ions tend to diffuse from the surface of the particles to the soil solution where their concentrations are lower. The potential difference between the surface of the particles and the external solution is called electrokinetic potential, or Zeta potential (ζ). This is an important electrostatic parameter for the particles suspended in an aqueous medium as an index of evaluating the stability of the suspended colloidal dispersions with respect to particle aggregation (Kim and Sansalone, 2008).

As a result of an increased concentration of electrolytes in half the increased amount of adsorbed ions in the fixed layer, the ζ decreases and the diffuse double layer shrinks. Under this condition, the micellar particles approach each other sufficiently that short-range attractive forces hold them together (Malvern 2004). In this case, the stability of the suspension has diminished with respect to the total dispersion and this is known as the flocculated state.

Briefly, it can be added that the kinetics of the particles caused by successive repulsions with other particles of similar load is what keeps them in suspension, resulting in colloidal dispersion. If the medium in which particles are located is modified so as to reduce the ζ, collisions will be weaker and the movement of the particles will have a lower intensity. If ζ continues to decline, eventually the particles cannot repel, hence they approach, bind and flocculate. In order to reach the state of flocculation, ζ does not necessarily need to drop to zero until a certain value such as "critical value" or "critical potential" of a specific colloidal suspension. Besides being determined by the concentration of ions adsorbed, the magnitude of ζ potential depends on the ion potential of the ions adsorbed. These factors are critical in the dynamics of soil nutrients and merit study (Mantilla et al., 2008).

In most soils, the ζ is negative because the ground surface is usually negatively charged and with increase in acidity the ζ negativity decreases and, in some cases, can achieve a positive charge (de la Rosa et al., 2007). These changes affect the rate of electroosmotic flow and it has been observed that the flow rate decreases as the pH of the electrolyte is around neutrality or if the alkalinity increases (Shapiro and Probstein 1993; Hamed and Bharda 1997). In research to describe the effects of pH on the ζ potential, artificially contaminated kaolinite was used which does not always behave like clays (eg., and benthic and lithic soils show no effects of changes in ionic concentrations of saturating fluids (Malvern 2004). The aim of this study was to determine a general correlation between parameters of moisture, pH and zeta potential (ζ), the latter two being measured in the saturation extract of three soils dedicated to the cultivation and production of barley (Hordeum distichum) malting, in order to develop a rapid and simple method of estimating the quality of this type of soil. Specific objectives of the study were to determine the saturation extract of pH, redox potential (Eh) and the ζ and in the solid phase, bulk density (δ), field capacity (CC), moisture content (W), organic matter (OM) and texture and correlations were established by using the resulting values.

Material and methods

Figure 1 shows a general location map of the study area and location points (Table 1) of sampling plots in savanna soils in the three municipalities. In each, soil samples were taken at random at different points (plots) to form a composite sample with respect to Municipality. Sampling was conducted four times a year (2011), in the months of February, May, August and November.

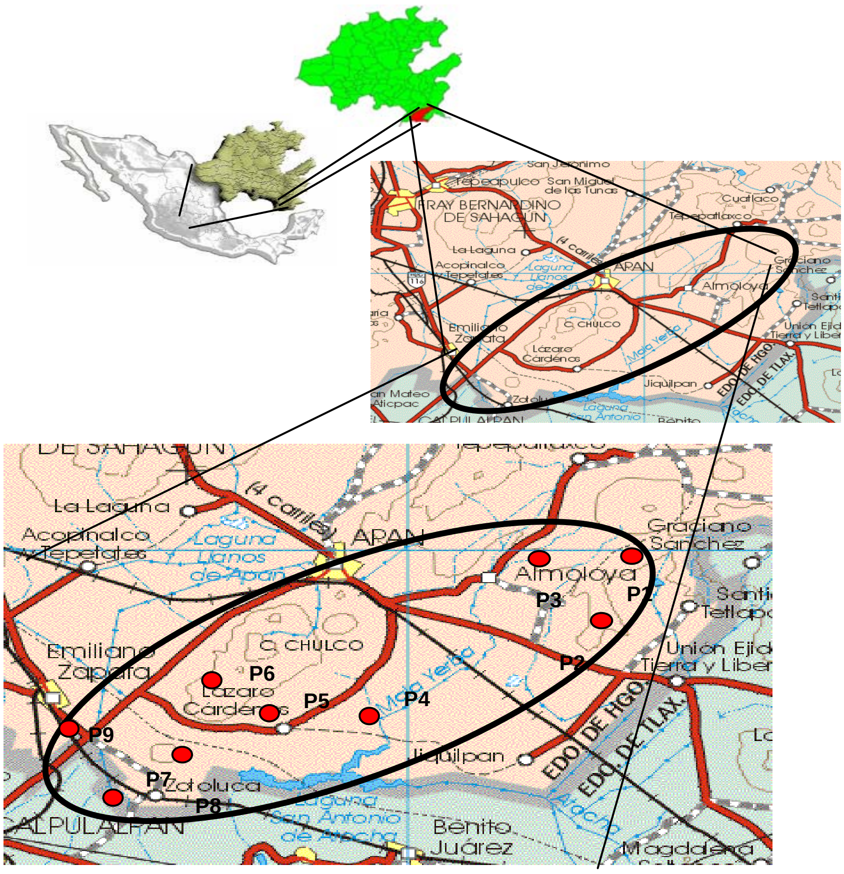

Fig. 1. Map showing location of the study area. Municipalities of Apan, Almoloya and Emiliano Zapata. Sampling points in the study area. Municipality of Almoloya (Plots P1, P2 and P3); Municipality of Apan (Plots P4, P5 and P6) and Municipality of Emiliano Zapata (Plots P7, P8 and P9).

Tab. 1. Location of sampling sites for the municipalites

Region	Location	Latitude	Longitude	Altitude [m]	Temperature [ºC]
1	Almoloya	19° 45’ 14.4”	98º 21’ 57”	2 730	12.2
2	Apan	19° 41’ 16.6”	98º 23’ 33”	2 547	14.1
3	E. Zapata	19° 54’ 16.0”	98º 53’ 4”	2 355	15.4

The soils were dried in trays and plastic bags placed in the sun. They were then manually cleaned of all foreign objects, chaff, stones or insects. Once dried and cleaned, they were reserved for signature analysis, based on saturation extract, pH determinations (NOM 021 SEMARNAT 2000) and zeta potential (ζ) (Malvern, 2004).

Particle size distribution in the colloidal saturation extracts was also analyzed, by laser diffraction using a size analyzer, Beckman LS Coulter 13-320 (Prieto et al., 2006). Bulk density was determined (δ) directly from the soil sample using the cylinder method (Blake and Hartge, 1986, USDA-NRCS, 1999). Field capacity (% CC) was also determined directly using the hose (soil column) method (Soriano and Pons, 2001). The following formula was then used:

$$\%CC = [(Psh - Pss)/Pss]*100$$

where

Psh is wet soil weight [g]

Pss is dry soil weight [g]

According to the texture class to which it belongs, a particular soil may considered using the following allowable ranges of CC (Table 2):

Tab. 2. Relationship of texture and field capacity [% CC].

Textural class	Field capacity [%]
SAND	< 5 – 16.0
SANDY LOAM	15.0 - 30.0
SILTY LOAM	30.0 - 45.0
CLAY	45.0 - 60.0

Moisture (w) and texture were determined using NOM 021 SEMARNAT 2000.

Results and discussion

Characteristics such as pH and zeta potential (ζ) of soils tested showed some similarities within the regions studied. From PH values, studied soils were classified as neutral (NOM-021-SEMARNAT-2000, Boulding, 1995), although soils of Almoloya rated as moderately acidic, characteristic of arid zones, favoring barley cultivation (see Table 3).

Tab. 3. pH, redox potential (Eh) and Zeta potential (ζ) in saturation extracts of the soils under study. Average values of the four sampling days (standard deviation).

Parcels by Municipality	AVERAGE VALUES		
	pH	Eh [mV]	ζ [mV]
Almoloya (P1)	6.44 (0.093)[a]	-21.42 (1.952)[a]	-26.50 (1.977)[a]
Almoloya (P2)	6.30 (0.085)[a]	-20.02 (1.463)[a]	-24.74 (2.005)[a]
Almoloya (P3)	6.32 (0.072)[a]	-20.79 (1.415)[a]	-25.71 (1.889)[a]
Average	**6.35 (0.081)[a]**	**-20.41 (1.707)[a]**	**-25.24 (1.963)[a]**
Apan (P4)	6.75 (0.094)[b]	-27.82 (1.582)[b]	-20.87 (1.742)[b]
Apan (P5)	6.86 (0.104)[b]	-28.12 (1.476)[b]	-21.09 (1.662)[b]
Apan (P6)	6.81 (0.090)[b]	-28.00 (1.588)[b]	-21.01 (1.605)
Average	**6.81 (0.076)[b]**	**-27.98 (2.646)[b]**	**-20.99 (1.638)[b]**
E. Zapata (P7)	6.74 (0.085)[b]	-27.74 (1.674)[b]	-18.51 (0.544)[c]
E. Zapata (P8)	6.72 (0.080)[b]	-27.91 (1.623)[b]	-18.13 (0.498)[c]
E. Zapata (P9)	6.81 (0.092)[b]	-28.15 (1.578)[b]	-19.02 (0.520)[c]
Average	**6.76 (0.038)[b]**	**-28.59 (2.111)[b]**	**-18.73 (0.514)[c]**

Various letters in columns: Significant differences ($p < 0.05$)

Redox potential (Eh) values with corresponding pH values and values that define the character associated with oxidizing or reducing soils indicate that soils of the areas evaluated are slightly reducing (Tab. 3). Similarly, zeta potential values (ζ) in saturation extracts show how the soils with colloidal suspensions of particles have low to moderate stablility (Malvern, 2004). These results and classification criteria are reported here for the first time for these lands devoted to the cultivation of malting barley. Shown in Figure 2a and 2b the correlations and correspondences between pH values - Eh and pH - pZ.

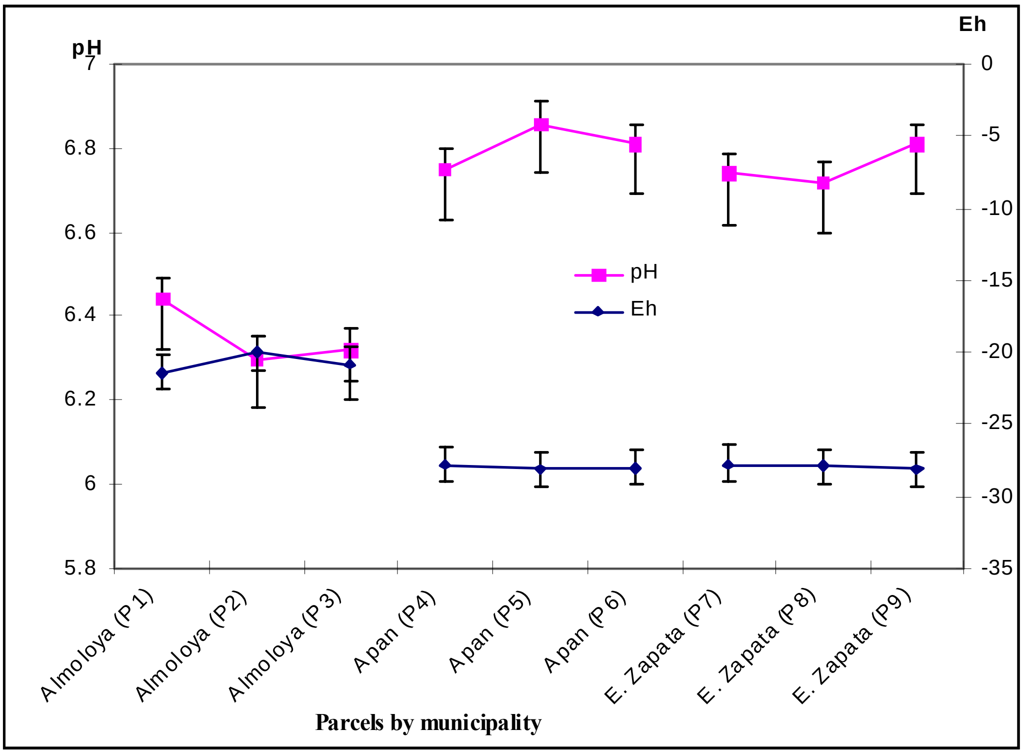

Fig. 2. a) Correlations of Eh vs pH from averages of four samples for the year for the plots of the three municipalities under study

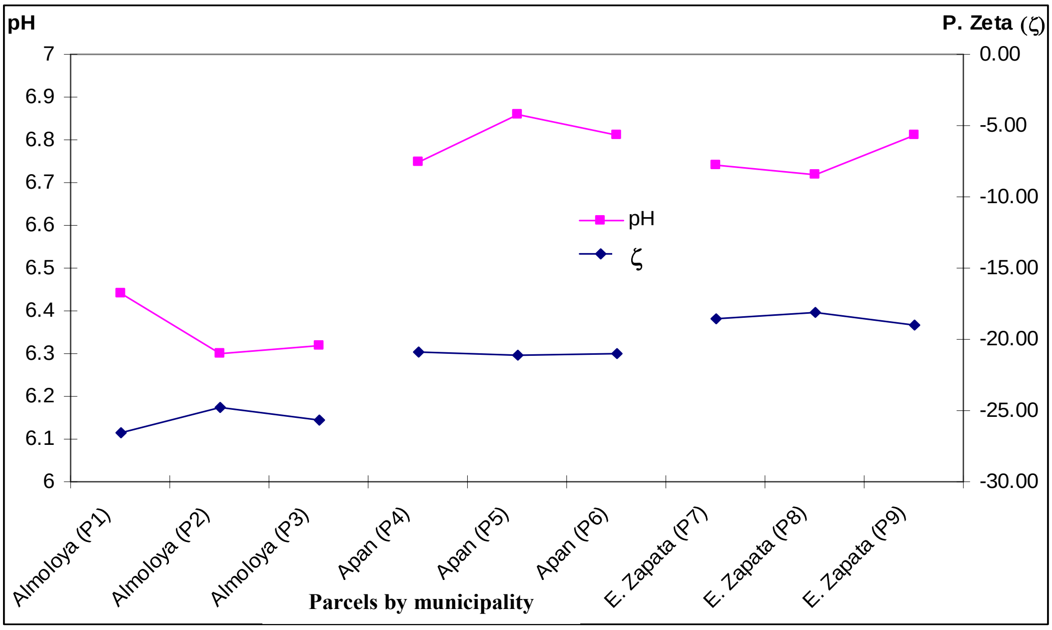

Fig. 2b). Correlations pH vs ζ from averages of four samples for the year for the plots of the three municipalities under study

Soil stability serves as a qualitative indicator of biological activity, energy flow and nutrient cycling development and aggregation of soil particles must be constantly renewed by biological processes (USDA, 2000). Almoloya soils (pH = 6.35) on average showed the lowest value of ζ (-25.24 mV), implying greater stability of colloidal fractions in this soil and it is appropriate to indicate that values < -30 mV indicate a high stability colloidal fractions in the liquid phase of the soil (Malvern, 2004).

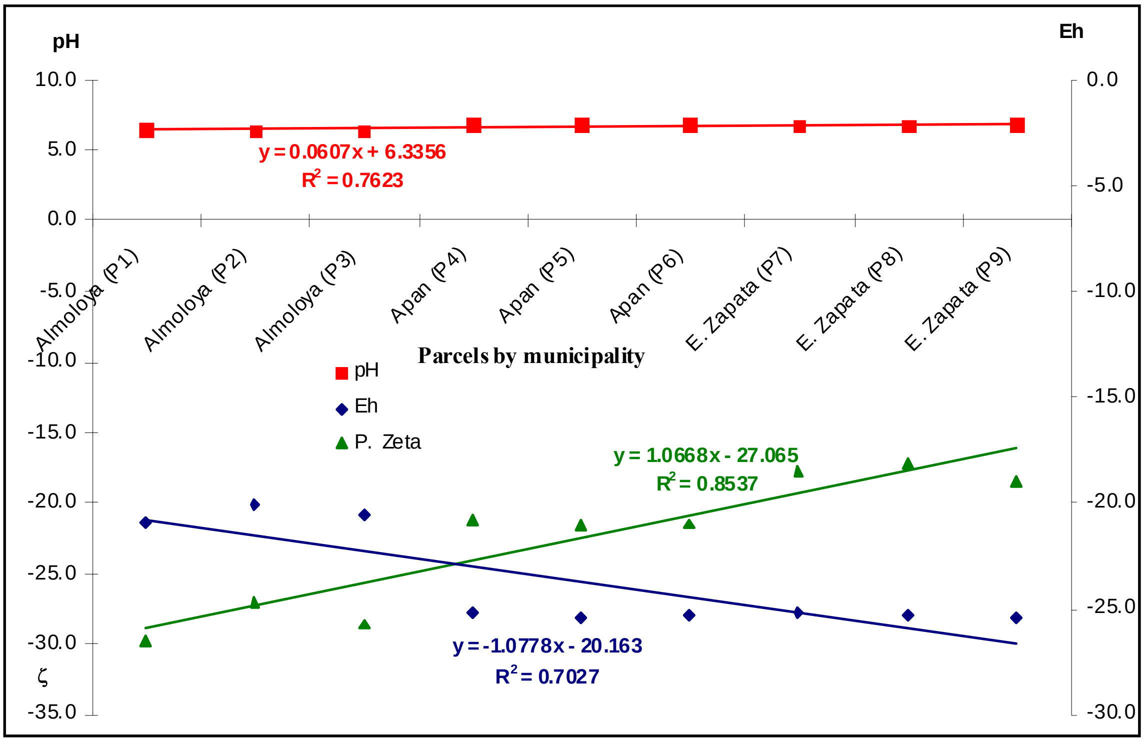

Fig. 3. Correlation linearity) averages of Eh vs pH b) averages of pH vs. ζ.

Figure 3 demonstrates that regressions of approximately 0.70 % are achieved, despite being from different municipalities. These regressions indicate a similar trend in the three municipalities, which is over 50 %, perhaps because it is soil that has been dedicated for over forty years to a monocultural system (barley).

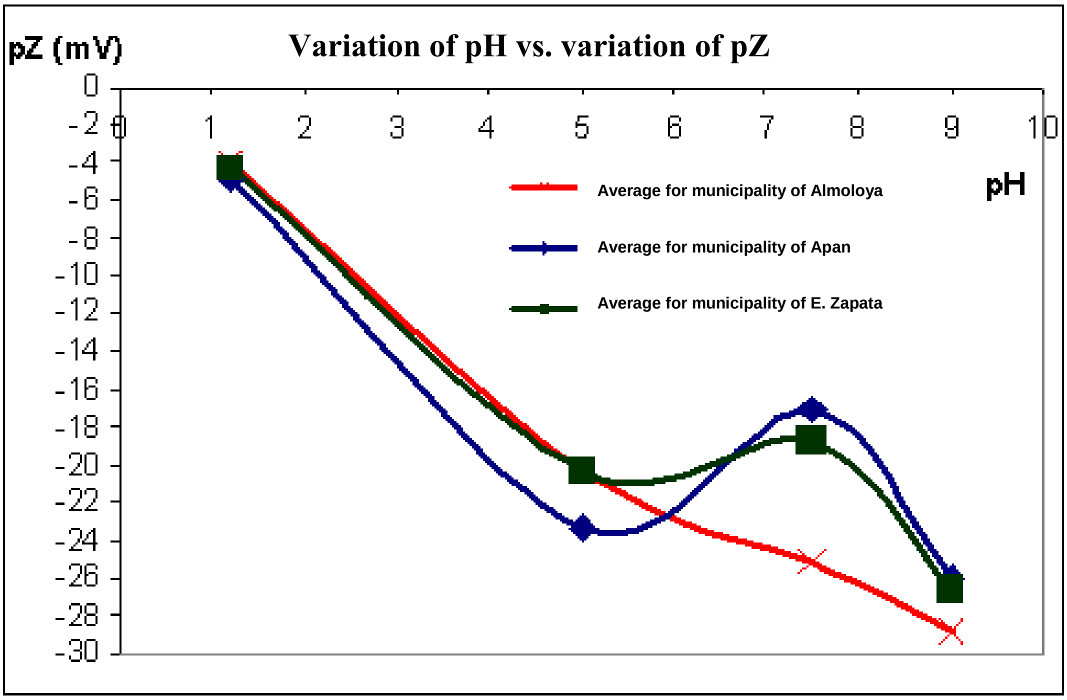

Fig. 4. Changes of ζ (averages per municipality) vs. pH.

Figure 4 shows variations in ζ to different pH values that were changed in saturation extracts to assess the stability of colloidal suspensions at different values of pH. It is noteworthy that the soils of Apan and Emiliano Zapata exhibit some instability of colloidal fractions at pH values close to neutral (pH = 7.5). This is associated with the highest content of dissolved salts (salinity) in these soils, consistent with that reported by Quiroga et al. (2001) and Galantini and Suñer (2008).

Tab. 4. Average values of texture, bulk density and field moisture capacity in the soils of the three municipalities.

Municipality	Average values of textures, moisture content, bulk density and field capacity							
	Texture	Sand [%]	Clay [%]	Lime [%]	Moisture content [%]	Organic Material [%]	Apar. Dens. [$Kg.m^{-3}$]	Field Cap. [% CC]
Almoloya	sandy-clay-loam[a]	16,94 (1,24)[a]	54,39 (1,96)[a]	28,67 (2,21)[a]	8.20 (0.52)[a]	6.34 (0.21)[a]	1325 (5.56)[a]	38.22 (0.75)[a]
Apan	sandy-clay-loam[a]	22,17 (1,88)[b]	55,17 (1,50)[a]	22,67 (2,31)[b]	10.20 (0.68)[b]	8.36 (0.33)[b]	1310 (4.97)[a]	40.06 (0.81)[a]
E. Zapata	sandy-clay[b]	62,83 (2,33)[c]	12,50 (1,63)[b]	24,67 (2,63)[b]	6.95 (0.47)[c]	4.97 (0.20)[c]	1608 (6.32)[b]	16.85 (0.62)[c]

Different letters in columns are significant differences (p <0.05)

Soils classified as sandy-clay-loam soils except for the municipality of Emiliano Zapata (sandy loam), thus presented the lowest moisture content (Tab. 4). Furthermore, for the soils of Emiliano Zapata, we noted the lowest content of organic matter (OM). Table 4 shows that Apan soils have higher values of MO, corresponding perfectly to soils with higher clay content, which justifies their higher moisture-retention capacity. It can also be seen that there is significant difference between the three soils in their sand content, and the clay content of the soils differs only for soils of E. Zapata and in silt content for soils of Almoloya.

Similarly, we can analyze the values of higher bulk densities (δ) corresponding to the sandier soils which coincide with the work of Daniels (1997) and are more compacted soils despite having lower moisture contents. With respect to field capacity (CC), soils of municipalities Almoloya and Apan (38.22 % and 40.06 %, respectively) correspond to the characteristics of these textures (sandy-clay-loam), and have lower δ values with relative increase in CC values, in agreement with findings of Kay and Van den Bygaart (2002) and Murray et al. (2011). The lower % CC values correspond to soils of the municipality of E. Zapata (16.85 %), and this being terrain of sandy loam, it is understandable that CC has the lowest values.

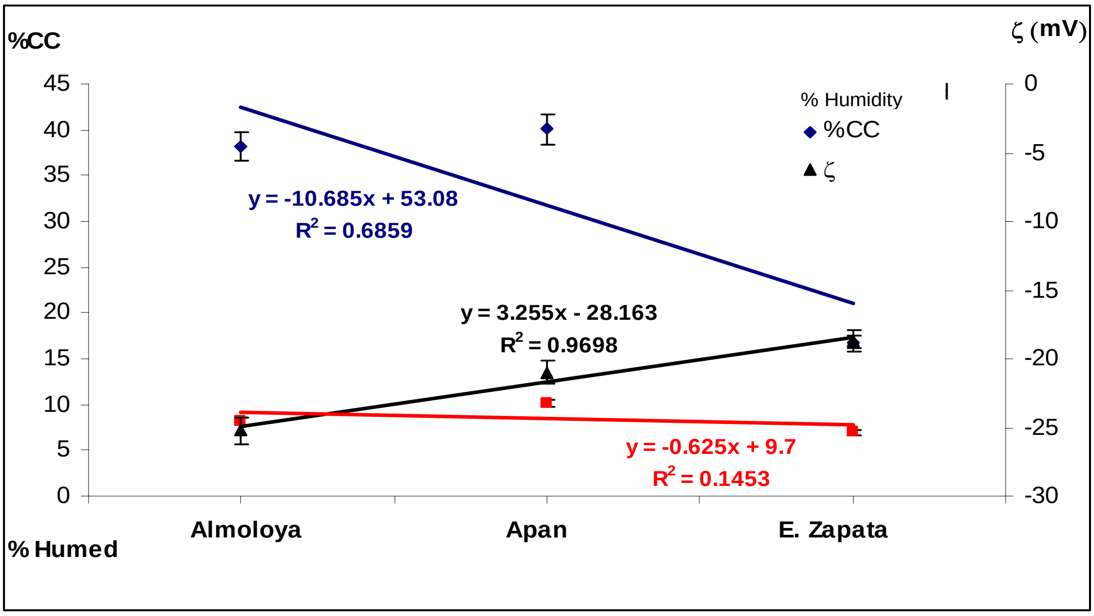

Fig. 5. Correlations between % CC, % moisture content and ζ (mV) in the saturation extract from soils in the three municipalities.

An interesting correlation can be seen in Figure 5 which shows that diminished % CC, diminishes the stability of the colloidal suspensions of soil (increase in ζ) concomitant with low soil moisture. This summarizes that lower quality soils are from the municipality of E. Zapata.

Conclusions

Stability of the colloidal suspensions of soils associated with colloids organic material is drastically decreased (thus, increasing the ζ), to the extent that there are decreases in % CC, clay content of the textural composition, therefore the moisture-retention capacity. In the plots of soils in the municipality of E. Zapata, will have the worst textures (lower % clay), lower humidity, the lowest loads of organic matter, the higher bulk density and lower field capacity. All this confirms that the plots are more compacted soils are less beneficial for growing barley in the southern region of the state of Hidalgo.

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