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Water retention and physical-chemical changes in a calcareous soil with application of a Mexican natural zeolite

Retención de agua y cambios físico-químicos en un suelo calcáreo con aplicación de una zeolita natural Mexicana

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Abstract

The objective in the investigation was to evaluate the water retention in a calcareous soil added with a Mexican natural zeolite. A natural zeolite can absorb and retain large amounts of water. Four treatments were tested; without zeolite application (T1-control), with application of 5 ton ha-1 (T2), 10 ton ha-1 (T3) and 15 ton ha-1 (T4) of zeolite. The experimental design was a complete block with four replicates. The percentage (%) of water retention in the soil was quantified on February 11, February 25, March 31 and April 12, 2021. Prior to the establishment of the experiment the soil (0-30 cm) was characterized by quantifying pH, electrical conductivity (EC), organic matter (OM), N, P, carbonates, bicarbonates and chlorides.

Zeolite, Soil, Humidity, Irrigation

Resumen

El objetivo de esta investigación fue evaluar la retención de agua en un suelo calcáreo adicionado con aplicaciones de una zeolita natural mexicana. Se probaron cuatro tratamientos; sin aplicación de zeolita (T1-testigo), con aplicación de 5 ton ha-1 (T2), de 10 ton ha-1 (T3) y de 15 ton ha-1 (T4). Se utilizó un diseño de bloques completos al azar con cuatro repeticiones. Se cuantificó el porcentaje (%) de retención de agua en suelo el 11 de febrero, el 25 febrero, el 31 de marzo y el 12 de abril de 2021. Previo al establecimiento del experimento se caracterizó el suelo (0-30 cm) cuantificando pH, conductividad eléctrica (CE), materia orgánica (MO), N, P, carbonatos, bicarbonatos y cloruros. Se encontró que una zeolita natural puede absorber y retener grandes cantidades de agua, para su uso potencial por los productores agrícolas mexicanos y reducir el consumo en los riegos de este vital líquido.

Zeolita, Suelo, Humedad, Riego

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Introduction

Zeolites were discovered approximately 260 years ago by the Swedish mineralogist and chemist Frederick Cronsted, who called them "boiling stones" because of the effect of expelling water when heated (Chávez-Aguirre *et al.*, 2019). In fact, he first used the word zeolite, which is a combination of two Greek roots; zeo meaning "to boil" and lithos meaning "stone" (Rojas-Nuñez, 2012). Zeolites are tectosilicates found in a wide variety of environments in the earth's crust (Inglezakis and Zorpas, 2012) and where the International Zeolite Association (IZA) has duly approved and validated around 176 zeolite types (McCusker *et al.*, 2007).

The most important natural zeolites are clinoptilolite, modernite, chabazite, phillipsite and scolecite among others (Wang and Peng, 2010). In the particular case of Mexico, Mumpton (1973) described for the first time the presence of mordenite and clinoptilolite in the Etla population in the state of Oaxaca. Later, deposits were reported in the states of Sonora, Puebla, San Luis Potosí and Chihuahua, among others (Ostrooumov, 2011). Despite these first finds in Mexico, zeolites were not considered in the Mexican mining statistics yearbook (Casals, 1988).

Zeolites possess three characteristics that make them very useful in various sectors: efficient absorption, high ion exchange capacity and a dynamic dehydration-rehydration process (Bilbao-Chávez *et a*l., 2019). These advantages have allowed its use as an alternative medicine in humans (Rubio *et al.*, 2019; Jevtic *et al.*, 2012), as a food supplement in animals (Mora *et al.*, 2018; Ruiz *et al.*, 2007), for the removal of pollutants in water (Miramontes-Gutiérrez *et al.*, 2021; Rubio-Arias *et al.*, 2021) and even as a construction material to improve thermal insulation (López Aguilar *et al.*, 2019). Undoubtedly, the existence of zeolite deposits throughout the world and, particularly in the case of Mexico, which, to date, has large deposits throughout the country, has opened up its potential use in various sectors.

However, few studies have documented the advantages of zeolite application under field conditions, in water retention and in the improvement of some physico-chemical properties of the soil.

For this reason, the objective of this study was to evaluate the water retention capacity of a calcareous soil added with various levels of zeolite. A second objective was to evaluate the change in the physico-chemical properties of the soil due to zeolite additions. These results allowed to identify the real advantages of calcareous soils, added with a zeolite, for their potential use by Mexican agricultural producers.

This article first describes the methodology used for the evaluation of the various treatments with Mexican zeolite. The results section shows the results obtained for each treatment tested, and in the final section the conclusion as to the best treatment applied to the calcareous agricultural soil.

Methodology

An experiment was established under field conditions, on agricultural land (Farm No. 4) owned by the Faculty of Agricultural and Forestry Sciences of the Autonomous University of Chihuahua (UACH). This property is located at km 2.5 of the Delicias-Rosales Highway in the state of Chihuahua (28°11" North Latitude and 105°30" West Longitude), is part of the Irrigation District 005 (DR-005) in the state of Chihuahua and is located at 1,415 m above sea level.

The following four treatments were evaluated; without zeolite application (T1-test), with application of 5 ton ha-1 of zeolite (T2), with application of 10 ton ha-1 of zeolite (T3) and with application of 15 ton ha-1 of zeolite (T4). The treatments were established in a randomised complete block design with four replications. In each treatment, a composite soil sample (0-30 cm) was obtained for laboratory characterisation, where the concentration of pH, electrical conductivity (EC), nitrogen (N-total), phosphorus (P), potassium (K), iron (Fe), zinc (Zn), copper (Cu) and manganese (Mn) parameters were detected.

For pH determination, the soil was first sieved through a 2 mm sieve. Then, in a 500 ml beaker, the sieved soil was mixed with distilled water to saturation point and the mixture was left to stand for 24 h. Finally, the pH was determined with a pH meter. Finally, the pH was determined with a Thermo Scientific multiparametric potentiometer.

Once the pH was determined by the saturation method, the paste was sent to the extraction machine in order to quantify the EC value using a Thermo Scientific multiparametric conductivity meter and, in addition, the extraction was used to determine the percentage of nitrogen, carbonates and bicarbonates.

For the quantification of the N parameter, the Soil Testing laboratory method (Soil Testing laboratory, 1980) was used, for which 1 pinch of calcium chloride (CaCl2) was added to a small amount of extract which was previously stored and shaken until dissolved. 1 ml of the mixture was poured into a 100 ml beaker, 3 ml of a mixture of sulphuric acid (H_2SO_4) and salicylic acid ($C_7H_6O_3$), sodium hydroxide (NaOH) and made up to 50 ml and allowed to stand for 30 min in the extraction chamber (Head, 1980).

For the P parameter, Olsen's method was applied, by which 40 ml of sodium bicarbonate ($NaHCO_3$), 1 pinch of activated carbon and a control without soil were added to a 250 ml Erlenmeyer flask and shaken for 20 min. After 20 min, it was filtered. In a 500 ml volumetric flask of the sample with soil, 5 ml of reagent mix was added to a 500 ml volumetric flask, allowed to stand for 3 min and volumetrically diluted with distilled water. The determination of N-total was quantified according to the method suggested by the Soil Testing Laboratory (Soil Testing Laboratory, 1980). One pinch of calcium chloride (CaCl2) was mixed in a small amount of extract, which was previously stored and stirred until dissolved. Then, 1 ml of the mixture was poured into a 100 ml beaker and 3 ml of a mixture of sulphuric acid (H_2SO_4) and salicylic acid ($C_7H_6O_3$), sodium hydroxide (NaOH) and made up to 50 ml and allowed to stand for 30 min in the extraction chamber (Head, 1980).

Land preparation, sowing and application of the field treatments were carried out in December 2020. The crop used was alfalfa (Medicago sativa L.) and the first irrigation was carried out on 11 February 2021. Soil samples to quantify the moisture content in the treatments were taken on the following dates in 2021; 11 February, 25 February, 31 March and 12 April. Once the samples were collected, they were weighed and placed in a drying oven for a period of 24-48 hours at 105° C, weighing them frequently until no variation in weight was observed.

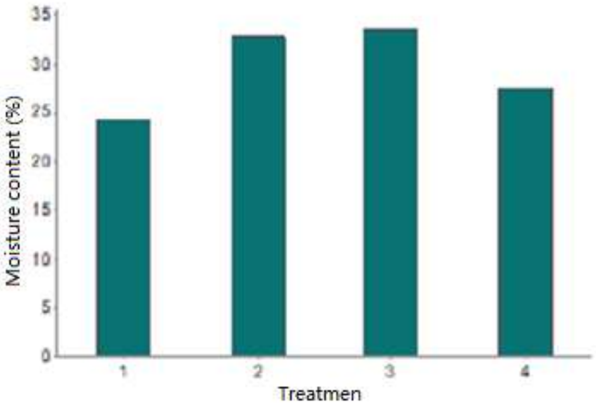
The percentage moisture content (%H) was obtained by the difference between the weight of the wet soil (SH) and the weight of the dry soil (SS). That is to say; %H=(SH-SS)/SS x100 (1)

The information was recorded in a database and statistical analyses were performed using Minitab software. A regression analysis was carried out for the treatments evaluated.

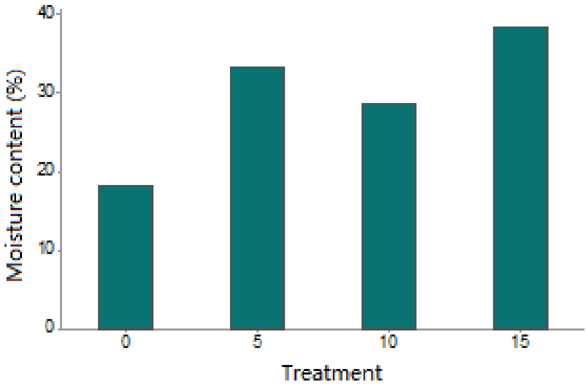
Results

On the first sampling date, there was a tendency for the percentage of moisture to increase as the amount of zeolite applied increased. Graph 1 shows this behaviour, where it is noticeable that the highest percentage of moisture retained by the soil was obtained with the application of 10 T ha-1 of zeolite (T2) with 33.6%, followed by the treatment with 5 ton ha-1 (T2) with 32.8%. It is also irrefutable that the control treatment (T1) presented the lowest percentage of water retention with 24.1%.

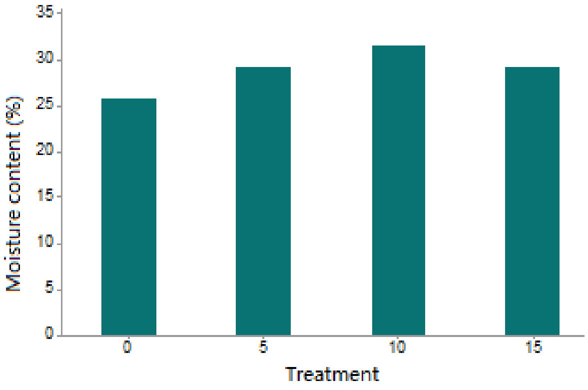
The results of the second sampling can be seen in graph 2. It is evident that the treatment with the highest zeolite application (T4) presented the highest percentage of moisture with 28.0%, compared to T1, which presented the lowest percentage with 13.2%. Graph 3 shows that all treatments with zeolite application (T1, T2 and T3) presented higher soil moisture percentages, compared to the control treatment, which had 25.7% moisture. The results of the fourth sampling are shown in Graph 4, where it is clear that the lowest percentage of moisture was in T1 with 11.4%, compared to T2 with 18.0%, T3 with 14.6% and T3 with 12.9%.



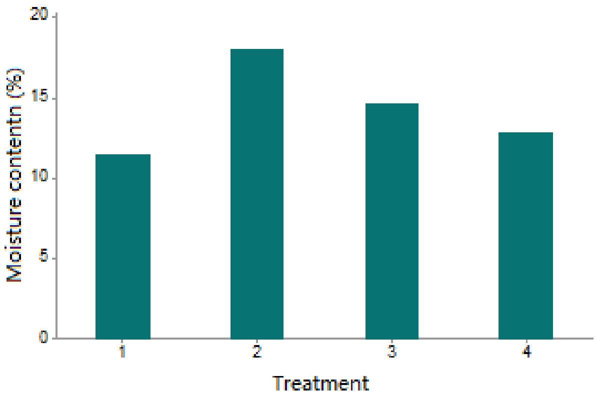
Graph 1 Moisture content in four treatments with natural zeolite applications (First sampling)



Graph 2 Moisture content in four treatments with natural zeolite applications (second sampling)



Graph 3 Moisture content in four treatments with applications of a natural zeolite (Third sampling)

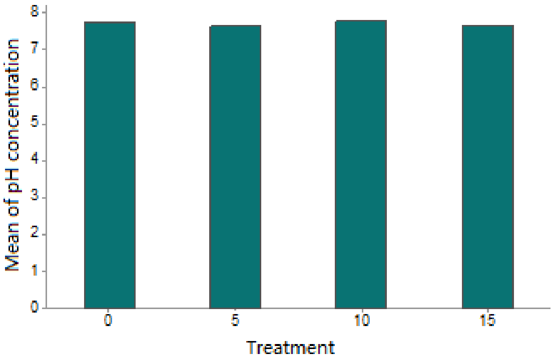


Graph 4 Moisture content in four treatments with applications of a natural zeolite (Fourth sample)

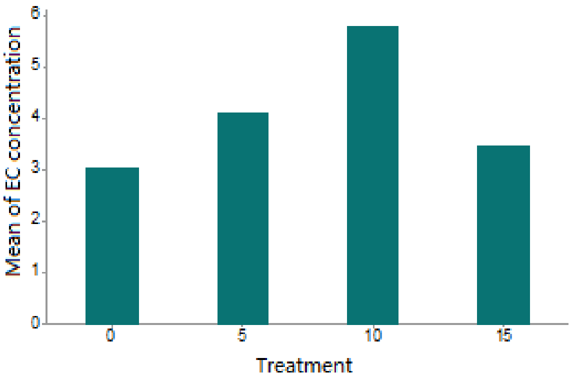
Soil pH and EC concentration

In this study, no statistical differences were found in the soil pH value among the four treatments evaluated ($P>0.05$). The lowest value of 7.6 was observed in T2 and T4 while the highest value of 7.8 was observed in T1 (control) and in T3 which received 10 ton ha-1 of zeolite (Figure 5). This slight increase in pH could be explained by a higher concentration of Ca, Na and $CaCO_3$.

The EC concentration was statistically different among the treatments evaluated ($P<0.05$). Figure 6 shows that T2, T3 and T4 exceeded the EC concentration in the control (T1) which was 3.0 mS/m. The highest concentration of 5.8 mS/m was observed in T3, attributing this result to a greater amount of salts such as Ca, Na and CaCO3, which favoured a higher EC concentration.



Graph 5 Average soil pH levels in four treatments applying a natural zeolite

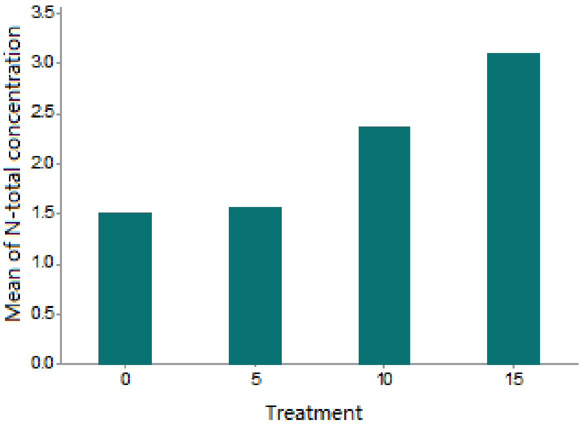


Graph 6 Mean EC concentration in soil in four treatments with application of a natural zeolitel

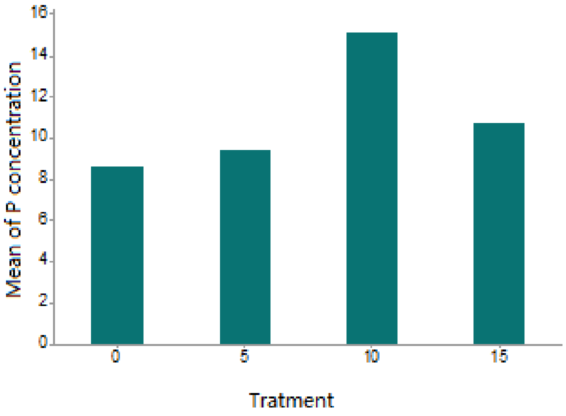
Concentration of N-total, P and K in soil.

The mean N-total concentration was statistically different between treatments ($P<0.05$). Graph 7 shows a linear trend as more zeolite was applied. It is noticeable that the concentration in all treatments was less than 3.0 ppm, which indicates a soil deficient in this element. It is important to note that zeolite application and its effect on N availability is controversial. The results of this study agree with those suggested by Gilloway *et al.* (2003) who observed an increase in N availability as high levels of zeolite were applied to the soil; however, researchers Tarkalson and Ipólito (2010) mentioned that the results with zeolite application were not consistent.

With respect to P concentration, it can be seen in Graph 8 that the mean concentration was higher at T3 with 15 ppm. It is interesting to note that the concentration of this element tended to decrease in T4 compared to T3, i.e. a quadratic effect between treatments is observed. In relation to soil K concentration, no statistical differences (P>0.05) were found between treatment means. The K concentration was very similar between the treatments studied, in a range of 90 to 95 ppm, so it can be asserted that zeolite does not contribute to the availability of K for plants in calcareous soils.



Graph 7 Mean total N concentration in soil in four treatments with application of a natural zeolite



Graph 8 Mean P concentration in soil in four treatments with application of a natural zeolite

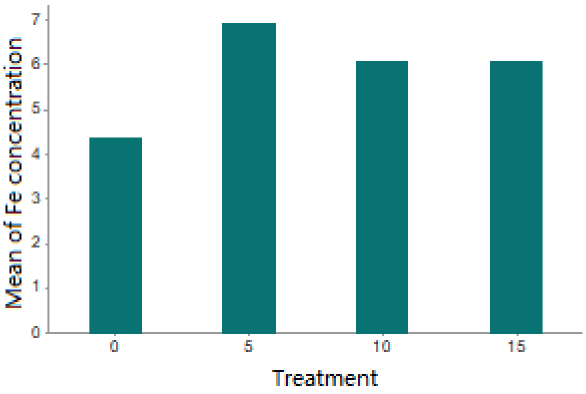
Concentration of Fe, Zn, Cu and Mn in soil

The mean Fe concentration among the treatments evaluated ranged from 2.5 ppm in the control to a concentration of 4.5 ppm in the treatments in which zeolite was applied (Graph 9), with statistical differences between treatments (P<0.05).

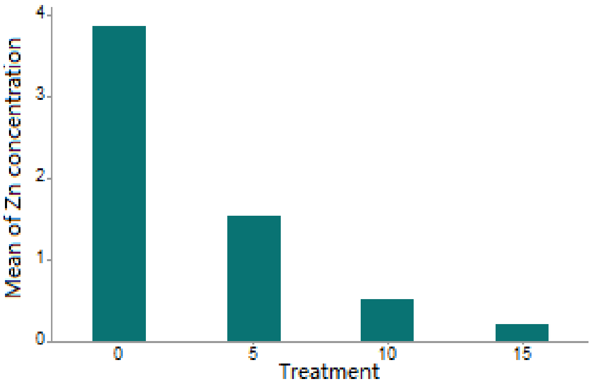
It is noticeable that in T4 the concentration of available Fe decreased slightly, so this effect can be attributed to the alkaline pH of the soil under study, which may have lowered the available Fe, since the availability of this metal in soil is minimised in alkaline soils (Prochnow *et al.*, 2009). The mean Zn concentration was higher in T1 (3.9 ppm) and T2 (1.4 ppm) than in treatments T3 and T4, which had higher amounts of zeolite (Figure 10), and statistical differences were found between treatments (P<0.05). These results show that zeolite application is directly or indirectly affecting certain soil properties; in this case, in particular Zn availability. One of the possible reasons could be the presence of CaCO3 which affects the availability of this metal.

Regarding Cu concentration in soil, a similar response to Zn concentration was observed (Figure 11). The highest concentration of 5.8 ppm was found in T1 and was statistically different from the rest of the treatments (P<0.05) that received zeolite. In general, it is observed that Cu concentration decreases as zeolite application increases. These results clearly indicate that zeolite has an effect on the availability of Cu in the soil for the plant.

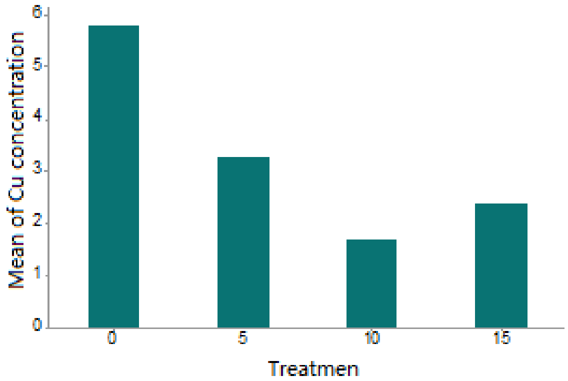
The concentration of Mn in the soil was higher in the treatment that received 15 ton ha-1 of zeolite with 11.46 ppm and no statistical differences were detected for this metal in the soil under the treatments studied (P>0.05).



Graph 9 Mean Fe concentration in soil in four treatments with application of a natural zeolite



Graph 10 Mean Zn concentration in soil in four treatments with application of a natural zeolite



Graph 11 Mean Cu concentration in soil in four treatments with application of a natural zeolitel

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Conclusions

The water holding capacity of a calcareous soil added with various levels of zeolite increased water uptake in the soils. As for the changes in the physico-chemical properties of the soil due to zeolite additions, it was possible to identify that the availability of Fe micronutrients increased, however, with the application of 15 tons per ha, the availability decreased with respect to zin and copper.

The total volume of water applied at a zeolite concentration of 20 tons per ha was lower than the other treatments that received a higher volume of water, however, this increase in zeolite concentration decreases the availability of micronutrients in this type of soil.

Therefore, the use of natural zeolite in calcareous soils allows the potential use by Mexican agricultural producers, reducing water consumption in irrigation.

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