World Journal of Agricultural Sciences 3 (3): 356-362, 2007
ISSN 1817-3047

Salt Leaching Process in an Alkaline Soil Treated with Elemental Sulphur under Dry Tropic Conditions

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Abstract: Soil drainage is necessary at both the field and district level to prevent rising tables and to allow for leaching salt. The laboratory study described in this paper was designed to evaluate the effect of elemental sulphur application on salts leaching in a tropical alkaline soil under dry tropic conditions. Four treatments were applied: (i) no-S°, (T_0), (ii) 0.5 mg $S°g^{-1}$ soil, (T_1), (iii) 1.0 mg $S°g^{-1}$ soil, (T_2), (iv) 2.0 mg $S°g^{-1}$ soil, (T_3). After mixing, subsamples of each soil mixture from each treatment were placed in plastic pots (30×30 cm, diameter × height) and maintained at 50% water holding capacity for 45 days at 28°C. After incubation, these soil subsamples were packed into polyvinyl chloride columns. Generally, cations with higher solubility (sodium and potassium) were strongly leached when the process was 1.3 pore volume, on the other hand, at the beginning of the process (0-0.25 pore volumes), calcium and magnesium cations were observed in higher quantities, although their values changed during the process. Anion composition in the effluent varied considerably during leaching, because carbonate quantities were low at the beginning of the process, although they later increased, contrary to sulphates, bicarbonates and chlorides. Sulphur application in soil increases anion and cation solubilization. This is evidenced by increase of electrical conductivity, as well as a higher pH in the soil without Sulphur application.

Key words: Leaching process · saline soils · alkaline soil · elemental sulphur · ions leaching

INTRODUCTION

Soil erosion, deterioration of soil structure, nutrients loss, build-up of salts and toxicants, waterlogging and desertification alone or in combination are contributing to soil degradation in most developing countries [1-3]. Two common causes of these problems include: use of poor water quality and inadequate agricultural practices, e.g. irrigation with high volumes of water [4], which may cause nutrient leaching loss [5]. Salt concentration in the surface or near-surface zones of soils contributes to land degradation, leading to falling crop yields and the loss of land for production in a range of environments. Human-induced salinization often referred to as "secondary salinization" to distinguish it from naturally salt-affected soils, is often cited as a major contributor to desertification processes in the drylands of the world [6].

Reclamation of salt affected soil is usually initiated by the downward displacement of surface-accumulated salts [7]. The fraction of salts removed from the top layers and the depth to which the salt peak is displaced during leaching determine the degree of reclamation which is largely governed by the quantity of water passed through the soil [8].

Drainage is necessary at both the field and district level to prevent rising tables and to allow for leaching salts. Since amelioration of saline soils depends on the movement of water through the soil profile to remove excess salts from the root zone, it is important that leaching and drainage for salinity control should (a) minimize flow of water through the soil profile to reduce dissolution of soil minerals and (b) reduce drainage volume [9].

Present irrigation practices in many areas are inefficient and unintentionally promote excessive

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leaching. This leads to a loss of water, energy and nutrients, deteriorates water quality and increases the need for drainage facilities [10]. For the previous reasons, when leaching process is going to be implemented, it is necessary to use products to prevent nutrients loss.

Several products have been used as soil amendments or to reclaim alkaline soils. Examples of these products are $CaCl_2$, H_2SO_4 and $CaSO_4$ [11], also organic amendments such as agricultural and industrial waste [12], including sewage sludge [13] and rice stubble. The application of manure by farmers often improves hydraulic conductivity and the use of products commercially available (e.g. polyalcohols and substances derived from humic acids) have shown promise, but their cost is high [14]. For many years, sulphur and sulphuric acid have been used for reclamation and improvement of alkaline soils [15].

Oxidation of S° to H_2SO_4 by soil microorganisms is particularly beneficial in alkaline soils to reduce pH, supply SO_4 to plants, improve soil structure and increase the availability of certain plant nutrients such as phosphorus, iron, manganese and zinc, etc. [16].

The Pacific coast of Western Mexico has an area of about 100,000 ha with soil alkalinity problems [17]. Farmers in this region are often sold products containing S° on the premise that they will lower soil pH and make nutrients more available. However, there are little research data with regard to improvement of these soils by adding soil S°, therefore, it is necessary to know, as well, what the salt displacement process is in soil when elemental sulphur is added.

The laboratory study described in this paper was designed to evaluate the effect of elemental sulphur application on salt leaching in a tropical alkaline soil in the Pacific coast of Southwestern Mexico.

MATERIALS AND METHODS

This study was carried out in laboratories of the Facultad de Ciencias Biológicas y Agropecuarias in the Universidad de Colima located in Tecomán, Colima, Mexico and this locality is in the Southwestern coast of Mexico.

Study site: An alkaline Orthic Solonetz soil [18] was collected from the coastal zone of Tecomán located 10 m above sea level, with annual mean temperature of 28°C and an average annual rainfall of 750 mm (Latitude 18° 52´N, Longitude 103°51´W) in the State of Colima, Mexico. Soil was collected from a depth of 0-15 cm, air dried for 72 h, sieved to 1 mm and mixed.

Treatments: Chemical properties of the original soil were first determined (Table 1). Following this, four treatments were imposed: (I) no-S°, (T_0), (ii) 0.5 mg S°g^{-1} soil, (T_1),

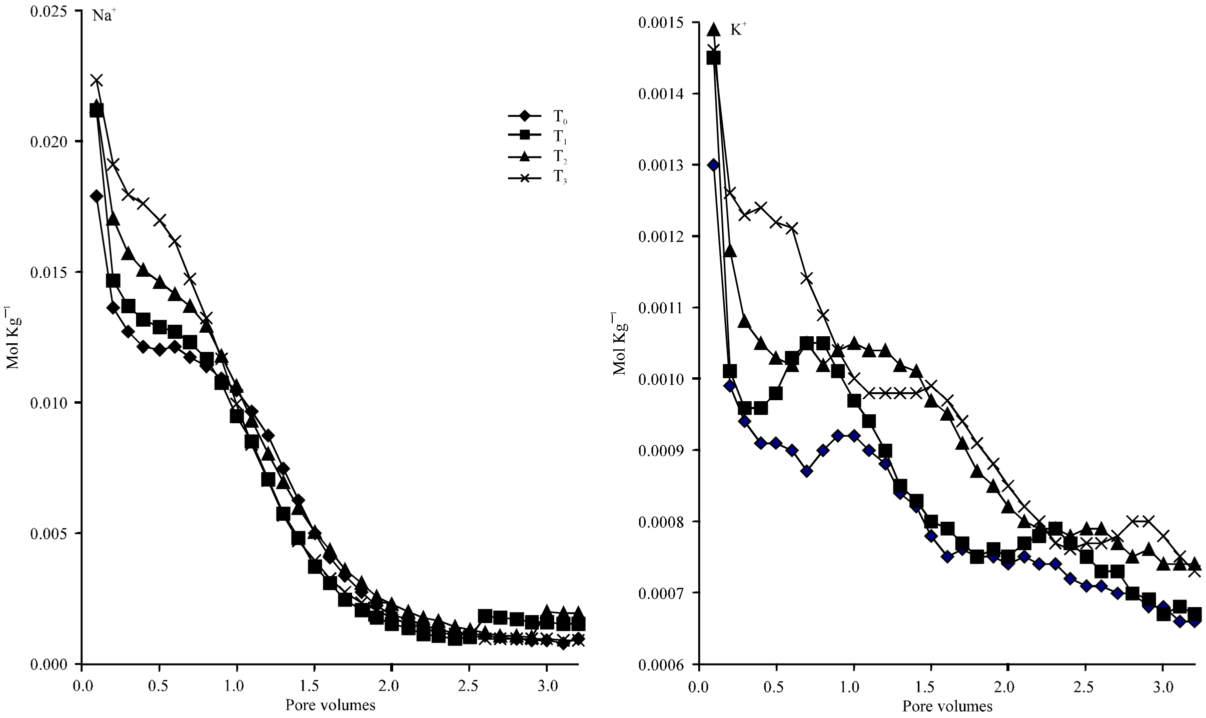

Fig. 1: Changes in Na^+ and K^+ concentrations in effluents in an alkaline soil treated with elemental sulphur

Table 1: Chemical analysis to the original soil, before sulphur application and leaching

pH	EC (dS m^{-1})	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+} (meq/100 g)	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-} (ppm)
8.5	1669	10.4	1.64	0.45	0.14	ND	0.16	3.24	1148.1

ND = Not Detected

(iii) 1.0 mg S°g^{-1} soil, (T_2), (iv) 2.0 mg S°g^{-1} soil, (T_3). Each experimental unit was replicated three times. Granulated S° (45-53 µm) was thoroughly mixed in a plastic bag with 5.2 kg of soil to each treatment. After mixing, subsamples of each soil mixture from each treatment were placed in plastic pots (30×30 cm, diameter×height) and maintained at 50% water holding capacity for 45 days at 28°C. After incubation these subsamples soils were packed into polyvinyl chloride columns (11.4×40 cm, diameter×height). Distilled water was added to each column until soil was under saturation conditions, approximately 1.2 L, this volume was designated as one single void volume [19]. Columns were subsequently leached with distilled water with amounts equivalent to 3-void volumes (3.6 L) over a period of six days in laboratory conditions (average temperature: 28°C). Water was added using a Mariotte beaker, as is shown in Fig. 1.

Chemical analysis: These analysis were done to each treatment both before and after applying sulphur to the original soil and to each 100 ml collected from the effluent to each treatment, this way, 36 effluents were analyzed since the beginning to the end of the experiment. In soil, the pH and electrical conductivity was determined in water by means of an extract with a 1:5 soil-to water ratio (w/v). Concentrations of specific soluble ions, were determined in an aliquot of the extract that was filtered through Whatman No. 2 filter paper and concentrations of Ca^{2+}, Mg^{2+}, Cl-and CO_3^{2-}, were determined by tritation; Na^+ and K^+ by flamometer and SO_4^{2-} by turbidity.

Statistical analysis: ANOVAs were made for each of the parameters estimated during the salt leaching processes and we used the SAS software version 6.12 [20].

RESULTS AND DISCUSSION

Cations leaching: The results of cation leaching process are shown in Fig. 1 and 2. Cations with greater solubility (sodium and potassium) were significantly leached when the process was in 1.3 pore volumes. Cations with lesser solubility (calcium and magnesium) had high initial concentration values at the beginning of the process (0-0.20 pore volumes) and their values varied during the rest of the process.

Sodium: Na^+ removed in soil treated with 2.0 mg of S° (T_3) had the highest values, at the beginning of the process (0-0.65 pore volumes), the total quantity Na^+ leached was bigger than the amounts of water-soluble Na^+ initially present in soil (FV = 10358.75, p = 0.0001). These results are similar to those obtained by Gupta *et al.* [21] who attribute it to greater mobilization of carbonates in an alkaline soil collected from a rice paddy. We observed the same phenomenon, because sulphur solubilized higher quantities of carbonates from the soil (Fig. 2). Solubilization of carbonates observed by Gupta *et al.* [21] was using organic manures to improve the soil quality meantime we used an inorganic product putting into the same focus.

Potassium: Values found for potassium were low both in soil and leaches. The highest quantities (0.0015 mol kg^{-1} in T_2) were leached at the beginning of the process. In treatments T_1 and T_2, when the process was in 0.5 pore volumes leaching values increased slightly and when the process was in 0.90 pore volumes in T_1 and 1.33 pore volumes in T_2, they decreased again (FV = 8.89, p = 0.0001). This may be due to hydrolysis of mineral containing potassium.

Results for cations are similar to those found by Heng *et al.* [5] whom used an undisturbed soil and Kosmas and Moustakas [22], whom employed an organic saline-sodic soil. In our work, magnesium was the cation with the highest quantities leached in the dynamics we speculate that it may be caused by solubilization of this cation from the mineral contained in the soil. In order to elucidate this hypothesis it is going to be necessary to conduct studies about the nature and kind of the mineral composition of soils in the Southwestern coast of Mexico.

Calcium and magnesium: These cations, were found in high quantities in the soil studied, it was also true due the values obtained from de leaches (Ca: FV = 150.26, p = 0.0001; Mg: FV = 1.18, p = 0.1333). This may be due to the possible presence of minerals containing magnesium and calcium carbonates in the soil, which were solubilized by the addition of S°, as proposed by Ryan and Tabbara [11] in the following chemical reaction:

$$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2$$

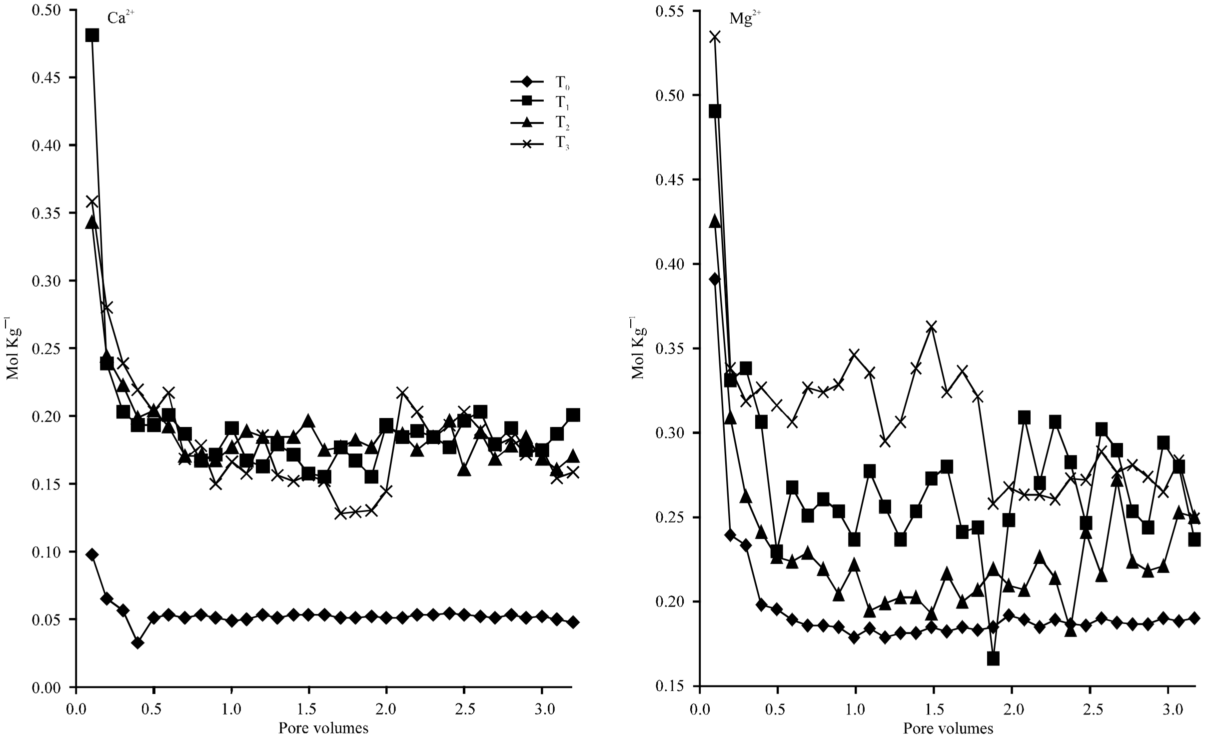

Fig. 2: Changes in Ca^{2+} and Mg^{2+} concentrations in effluents in an alkaline soil treated with elemental sulphur

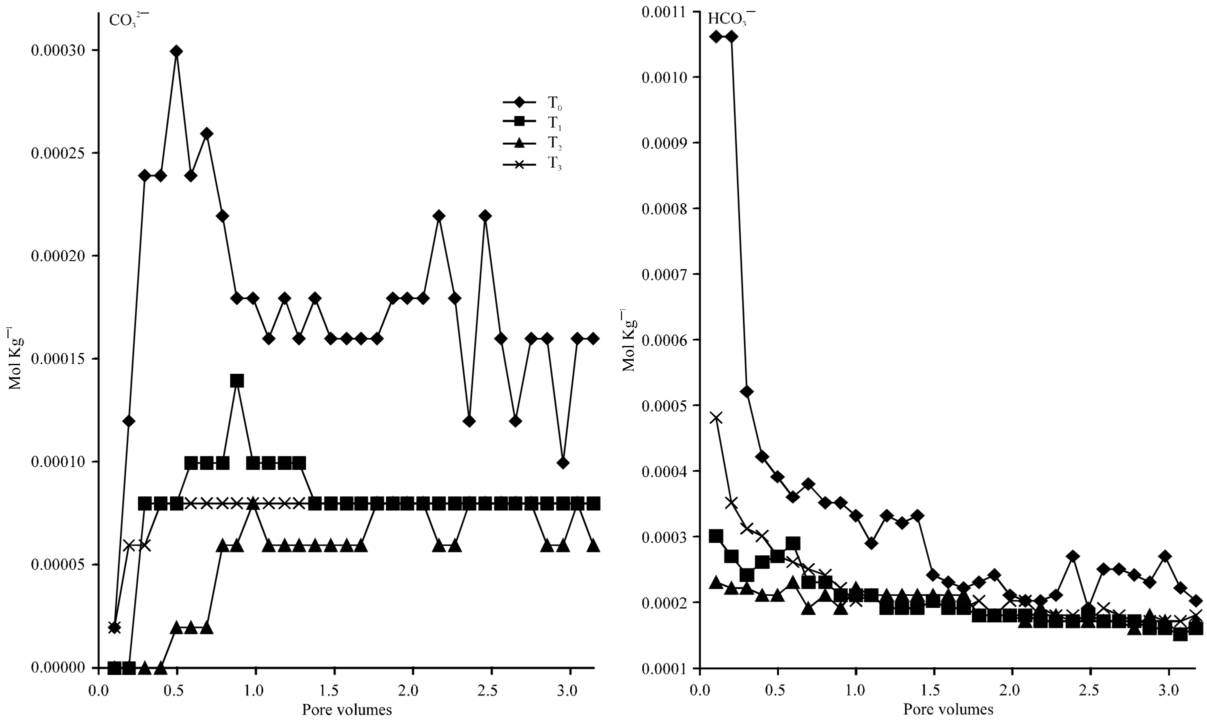

Fig. 3: Changes in CO_3^{2-} and HCO_3^{-} concentrations in effluents in an alkaline soil treated with elemental sulphur

$$H_2SO_4 + MgCO_3 \rightarrow MgSO_4 + H_2O + CO_2$$

The significantly lower calcium and magnesium cation concentrations in soil without sulphur (T_0) tend to support our observation. The difference between each treatment was greater for calcium, which also had the greatest concentration (Fig. 1). On the other hand, dissolved calcium in the soil phase probably replaced the sodium in the colloidal complex, this is supposed because the treatments with sulphur probably induced higher sodium leaching.

Anion leaching: The Fig. 3 and 4 show the results for anions in leaching process. The anion composition in the effluents in all the treatments varied considerably during leaching, since carbonate concentrations were too low at the beginning of the process and increased later, contrary to sulphates, bicarbonates and chlorides.

Sulphates: Treatment T_3 had the highest values (from 6000 to 3160 ppm) and T_0 the lowest (from 3350 to 1748 ppm), throughout the leaching process, which was expected (FV = 198.80, p = 0.0001). The increase of sulphates in leaches was proportional to the sulphur added to the soil. These results are similar to those found by Mc Lay *et al.* [23] in a repacked soil and by Eriksen *et al.* [24] in Danish soils, even when they did not added any product. According to López-Aguirre *et al.* [17], sulphur oxidation in soil was carried out by microorganisms present in soil.

Chlorides: Almost all chlorides were leached in all the treatments at the beginning of the process (0.03 pore volumen). The reason of this is that the salts containing potassium have a high solubility and they are rapidly leached (FV = 8948.14, p = 0.0001). Highest chloride concentrations were found in T_2 and T_3 treatments.

Carbonates and bicarbonates: Carbonates were not detected in the original soil, but found in the leaches. Soils where sulphur was added, had the lowest values, when compared to the control (FV = 1.0, p = 0.4982). This may be because microorganisms increase their population (according to Lopez-Aguirre *et al.* [17]) and they use CO_2 as a carbon source. These anions had the lowest values at the beginning of the leaching process and they increased when the process was 0.60 pore volumes in T_0 treatment and 0.90 pore volumes in treatments with sulphur, although they later decreased. We suggest that the cause of this reaction was that a bigger amount of carbonates were dissolved when water amounts added were higher. This is most probably because they have a low solubility. This last observation is offered to explain how carbonates leaching after 0.95 pore volumes had

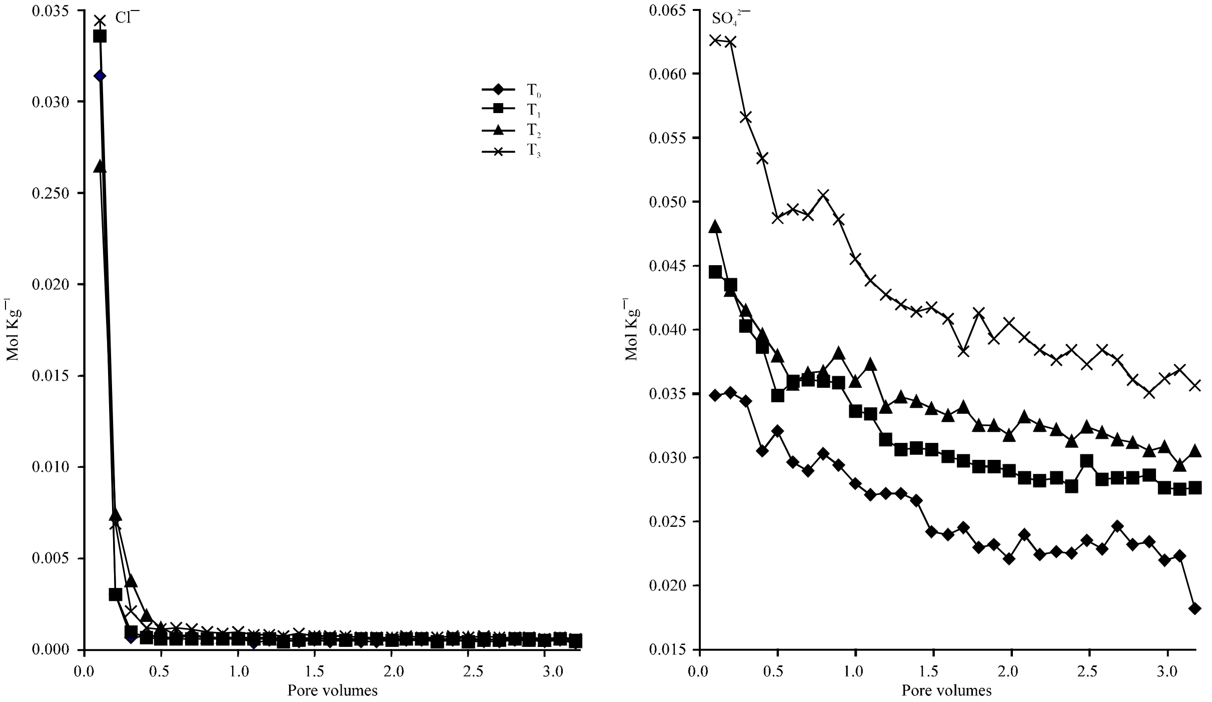

Fig. 4: Changes in Cl^- and SO_4^{2-} concentrations in effluents in an alkaline soil treated with elemental sulphur

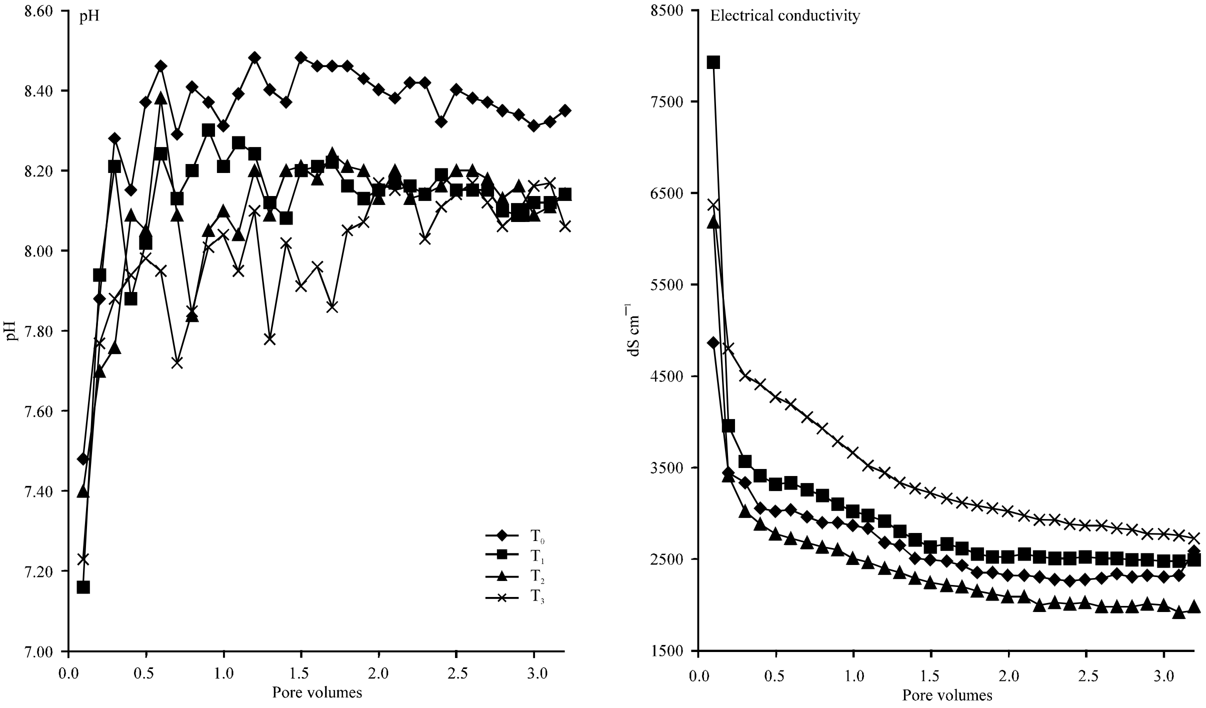

Fig. 5: Changes in pH and electrical conductivity in effluents in an alkaline soil treated with elemental sulphur

similar values in treatments with sulphur. On the other hand, leaching process was different with respect to bicarbonates since they had the highest values at the beginning of the process, yet the lowest where sulphur was added (FV = 4.52, p = 0.0001). The reason for this may be because bicarbonates have a higher solubility than carbonates.

pH and electrical conductivity: The pH in the control soil had the highest values (8.5) and T_3 the lowest (7.6). Similar to carbonates, initial values in the process were low, but increased to 0.9 pore volumes in all treatments. After this increase, the variations were not very significant (FV = 0.15, p = 1.0). In treatments with sulphur it is very probable that there was increased microbial activity which also resulted in increased CO_2 level in the leach, resulting in a lower pH than in the T_0, due to the lack of readily available energy source for the microbes and unfavourably high pH values, commonly observed in alkali soils, as proposed by Kosmas and Moustakas [22].

In all treatments, the initial pore volumes had a high salt concentrations, with T_3 having the highest value and T_2 the lowest value. We suggest that this was because the carbonate and bicarbonate hydrolysis was carried out in soil, maintaining a higher level of electrical conductivity in T_0 than in T_2 (FV = 20.36, p = 0.0001) Similar results were obtained by Rowel [25] and Miyamoto and Enriquez [26].

CONCLUSIONS

Sulphur application in an alkaline soil increased the solubilization of anions and cations and enhanced its salt leaching, it increased also the electrical conductivity and decreased the pH in comparison with soils without sulphur application.

ACKNOWLEDGEMENTS

This research was supported by a grant from the University of Colima. The authors thank M.Sc. Miguel Ángel Aguayo López and Ing. Lorenzo Hernández Arreguín for support this study.

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