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Salt Leaching in Sulphatic Soils of Palomas, San Luis Potosí, Mexico

E. I. Sánchez Bernal[1*], M. A. Camacho Escobar[2], N. Y. Ávila Serrano[2], A. Can Chulim[3] and H. M. Ortega Escobar[4]

[1]Institute of Ecology, Universidad del Mar Campus Puerto Escondido, Oaxaca, Mexico.
[2]Agricultural Sciences Program, Universidad del Mar Campus Puerto Escondido,Oaxaca, Mexico.
[3]Faculty of Agronomy, Autonomous University of Nayarit, Mexico.
[4]Hydrosciences Program, Postgraduate College, Montecillo, Mexico.

Authors' contributions

This work was carried out in collaboration between all authors. Authors EISB and HMOE designed the study, performed the data collection and analysis, draft of the manuscript and manuscript review. Authors MACE, NYAS and ACC managed the analysis of study, manuscript editing and review. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

The aim of this study was to evaluate the initial salinity and the type and amount of salt evacuated from soils of palomas, san luispotosí in a leaching process. These soils present primary and secondary salinization problems, induced by irrigation which affects their productive capacity. The study was conducted in a greenhouse and in the soils laboratory of the graduate college, from april to august 2010. Leaching of salts was done in soil columns that were applied with three soil-water extraction ratios, namely, 1≈0.2-0.6, 1:5 and 1:10, and the normal rates of leaching $\frac{Q_a}{Q_\pi} = 0$, 1.5 AND 3.0, where: q_a is the volume of water at which a soil reaches its saturation capacity, plus another equal volume, and so on. Q_π is the volume of water needed to make the soil reach its saturation capacity. This rate corresponds to volumes of water applied under field conditions of 1971.72 m^3 ha^{-1}, 2,957.58m^3 ha^{-1}, and 5915.16m^3 ha^{-1}, respectively. The initial salinity of each ratio was

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*Corresponding author: Email: edgarivansb@zicatela.umar.mx;

69.03 mgha^{-1}, 153.59mg ha^{-1} and 201.37mg ha^{-1}. The higher extraction ratio and rate of leaching applied, the higher the amount of soluble salts leached, and the lower the average residual salinity of 0-50 cm soil layer. At zero leaching level no leachate was obtained. The extraction ratio 1:10 and the rate of leaching $\frac{Q_a}{Q_\pi} = 3.0$, was significantly (*p*=0.05) outstanding. Under these conditions appreciable amount of salts were leached off the topsoil, especially nacl and na$_2$so$_4$. The residual salinity of the 30 cm soil layer was 1.68 g salt 100 g^{-1} of soil (109.48 mg ha^{-1}). This indicates desalination.

1. INTRODUCTION

The world distribution of arid and semiarid zones is approximately 324,921,000 and 558,697,000 ha respectively. These land surfaces are increasing due to the effect of agricultural irrigation [1]. In Mexico more than 65,000 ha of irrigated lands have salinization problems, causing food shortages which, ultimately, results in the migration of the rural communities affected [2]. The problem is aggravated by the opening up of new irrigated lands, so it is essential to understand the phenomenon that governs the accumulation process of salts in the soil [3]. A saline soil induces osmotic, toxic and nutritional deficiencies which adversely affect growth, development and yield of cultivated plants [4]. Essentially, the intensity of salt stress depends on the prevalence of certain specific ions found in both the solution and in the cationic exchange complex of the soil. This is linked to the type of physiological effect that is observed in the plants, which can be either osmotic (produced by NaCl salt in soils with hydrogen chloride salinity), or osmotic - toxic (produced by Na$_2$SO$_4$ and MgSO$_4$ salts in sulphatic soils) [5,6]. To mitigate the adverse effects of saline soils, corrective measures have been designed. One of the most frequently used to desalinate soil is the leaching of salts by running over irrigation water with a low electrolyte concentration (<200mS cm^{-1}) through the top most layer of soils, to decrease the original salt concentration and produce favorable abiotic conditions for growth and development of plant roots. However, this is only feasible when there is efficient natural or artificial drainage [7].

The soils of Palomas, San Luis Potosi, with an area of approximately 2000ha [8] are sulphatic salinity affected. In this area, maize (*Zea mays L.*), beans (*Phaseolus vulgaris L.*), tomato (*Lycopersicon esculentum L.*) and chili peppers (*Capsicum annum L.*) are cultivated and irrigated by saline waters. These waters originating from limestone aquifers (carzos) are obtained from semi-deep wells. Furthermore, the soils lack adequate natural drainage. These factors contribute to the salinization of the top soil layer where roots of crops develop. The objective of this study was to evaluate, under greenhouse conditions, a leaching process to remove salts in soil samples, using different ratios of soil - water extractants and active leaching volumes, in order to quantify the initial salinity, the salts extracted and the residual salt produced by leaching each thickness. Our hypothesis is that the ratio 1:5 soil-water extractant can leach a large quantity of salts within a thin water layer. Results will serve as a basis to project a more efficient leaching rate in the field and to propose that this technique, along with the application of chemical enhancers, be used as a temporary desalination alternative for the agricultural lands of Palomas, San Luis Potosi.

1.1 Theoretical Framework

The saline leaching of a soil consists of applying a certain volume of water to a soil thickness in the form of a hydraulic charge, with a free gravitational descent in order to achieve a descending displacement of salts. This involves the passing of a film of water periodically through the soil to the edaphic saturation point. To do this, it is necessary to take the soil to its saturation capacity ($Q\pi$) and record the volume required to establish the soil-water ratio $1 \approx 0.2$-0.6. Additional volumes needed to attain saturation will have a displacement effect of salts in a specific soil thickness, which constitutes a volume or active leaching norm $\left(\frac{Q_a}{Q_\pi}\right)$ [9]. During a salt leaching process, it is crucial to establish the initial salt reserves (I_s), as well as the residual salt reserves (R_s), that is, the amount of salts that remain in the soil profile after a leaching process. To evaluate the salt reserves in the soils, aqueous extracts are taken from different soil-water extraction ratios, including the following: $1 \approx 0.2$-0.6, 1:5, 1:10…1:n. In general, the choice of one of them depends on the type of investigation and experimental information desired [10]. Researchers such as Panin and Litovchenko, corroborated on the advantages of using the soil-water extraction ratios $1 \approx 0.2$-0.6 (known as saturation paste) and 1:5 in a leaching process, and indicate that the first displaces the easily soluble salts, but not those of medium or low solubility. On the other hand, the second ratio is considered adequate to evaluate salt reserves with high, medium, and low solubilities; both allow an objective analysis of the course of leaching [11,12]. González et al. and Sánchez et al., pointed out that by using aqueous extracts, it is possible to determine the salt content of soils in a representative manner [9,10].

This report established, first of all, the volume with which a soil sample contained in a column reaches the point of saturation $\left(\frac{Q_a}{Q_\pi}\right) = 0$. This point is reached by obtaining the first drop of the effluent. Secondly, the active leaching rates $\left(\frac{Q_a}{Q_\pi}\right) = 1.5 \ y \ 3.0$ applied, will indicate the volume required to lead the soil to its saturation capacity plus another one and half, and three additional volumes, respectively.

2. MATERIALS AND METHODS

2.1 Area of Study

The study area is located in the northern highlands of Mexico. The coordinates and altitude of Palomas intermountain valley, are 22° $29'05.83¨$N and 99° $51'$ $24.53¨$ W, at a height of 1026m (Fig. 1). The geology of the area is mainly calcareous and gypsum. The microbasin shares common boundaries with Matehuala-San Luis platform, Sierra Madre Oriental, Río Verde basin and Sierra El Tablón in the north, east, south and west respectively [13]. The relief is composed of flat lands with soft slopes (2°) which is part of the Río Verde-Matehuala basin. The soil texture of the area is silty clay derived from alluvial and colluvial tertiary calcareous sediment deposits. Furthemore, it is interspersed with soils of intermediate petrocalcic texture with gypsiferous horizon. According to FAO classification [14] and resolutions by Charcas et al. [8] they are vertisols and haplicxerols. Although these soils have low organic matter levels, they can sustain crops under irrigation. Some crops planted on these soils are maize, beans, tomatoes and chilli pepper.

The climate is dry with rains in the summer (Bs_o). The rainfall is roughly 517.2 mm, with an average temperature of 20.9ºC, a minimum of 18.1ºC and a maximum of 22ºC. Approximately 80% of rains fall between June, August and September. The vegetation is semiarid, with predominant microphyllic desert scrub, composed of mezquite (*Prosopis glandulosa)*, greasewood (*Larrea tridentata*) and tarbush (*Fluorensia cernua*). Another type of vegetation is made up of cactus (*Opuntia sp*) and lechuguilla (*Agave lecheguilla*), as well as halophyte shrubs (*Bouteloua sp*), and (*Aristida sp*).The soils are irrigated with well water and irrigation water of the Alaquines river, which discharges into the Palomas, endorheic basin. This water is mainly used for domestic, agriculture and recreational purposes [15].
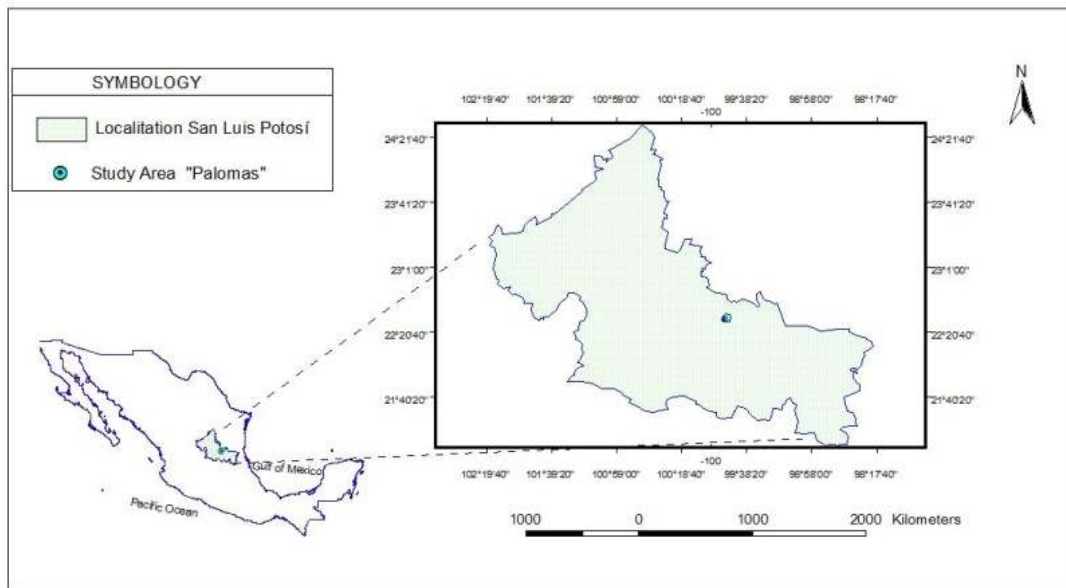

Fig. 1. Area of study

2.2 Sampling and Analysis of Soils, Waters, and Leachates

Soil samples were taken in the Spring of 2010. Given the homogeneity of the landscape, three profiles were established at random in zig-zag, at a distance of 800m, following the procedure of NOM-021-SEMARNAT-2000 [16]. Each profile was dug at a depth of 0.80m, and enough soil was taken for it to be packed into columns. Likewise, water samples from deep wells in Ejido Tablas, Agricultural Colony "La Morita" and Ejido "Palomas" were collected into 1 L previously washed polypropylene bottles. The soil samples were dried in the open air and later sieved through 2.0mm mesh and analyzed both in the Saline Soil and Water Laboratory of Postgraduate College and in the Aqueous Laboratory of Universidad del Mar. Parameters analyzed for water samples were pH and electrical conductivity EC (μS cm^{-1}) using a Hanna ® HI98129 multiparameter, sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP) and total solids dissolved (TSD in g L^{-1}) using dry calcinated residue (DCR) dried in a kiln at 600ºC, according to procedures of Manual 60 (U.S. Salinity Laboratory) [17]. Cations Ca^{2+} and Mg^{2+}, anions CO_3^{-2}, HCO_3^- and Cl^- were determined using the titrimetric method. Na^+ and K^+ were evaluated using Flame photometry (Flame photometer IL-653) and SO_4^{-2} were evaluated by spectrophotometry. Soil texture was determined by the Bouyoucos hydrometer method [18]. Wet and dry soil color, was

determined by Munsell color cards [19]. To evaluate initial and residual salinity of the soil columns, leaching was done at the soil-water extraction ratios 1≈0.2-0.6, 1:5 and 1:10, and their pH, EC and TSD determined. Also the osmotic potential (Ψπ) were determined using a VAPRO WESCOR ® 5100 osmometer. Soluble cations and anions were obtained using the procedure mentioned and SAR and ESP were calculated using the procedure in Manual 60 of the U.S. Salinity Laboratory [17]. The leachate were also analyzed using similar methods.

2.3 Experimental Setup

Nine polyvinyl chloride (PVC) columns sealed with paraffin were used to avoid the walls from overflowing during the leaching. The columns with an interior diameter of 18.5cm and a height of 70 cm were sealed at the bottom with Whatman No. 42 filter paper, and mosquito mesh, and were packed with 1.57kg of soil to the height of 5 cm to give an apparent density of 1.17g cm^{-3} and a volume of 15724.94 cm^3, to form a total thickness of 50 cm. Similarly, was prepared a column of the same diameter, 40cm tall and 20cm thick soil which served as an evaporation plate. The columns were placed over plastic funnels with a diameter of 25 cm, on two wooden tables that supported the columns in the green house. The leachate were collected into 250mL plastic containers. Metallic structures were adapted to the tables to fix the columns, as well as to hold the 1000mL Mariotte test tubes on top of them, which contained the water to leach. The test tubes were sealed with a rubber bung and connected to two glass tubes (1cm in diameter x 6.0cm long), and two rubber hoses (1.0cm in diameter x 30cm long), which help maintain a hydraulic load of 10cm with a vacuum effect, a way that the water will percolate in the soil. The load was constant during the entire process. The experiment was designed with three treatments $T_1\left(\frac{Q_a}{Q_\pi}\right) = 0\ (test)$, $T_2\left(\frac{Q_a}{Q_\pi}\right) = 1.5$ and $T_3\left(\frac{Q_a}{Q_\pi}\right) = 3$, in a randomized block and replicated three times to give nine columns. The leaching process was carried out with distilled water. The layer of leaching water were kept constant until the pore volumes of leaching water $\frac{Q_a}{Q_\pi}$ established. Daily temperatures were recorded with a minimum and maximum temperature thermometer. The daily evaporation of the water load of the columns was also found using the evaporation plate. The volumes evaporated daily were quantified using the following equation:

$$Evaporated film(mm) = \frac{E_v}{A}(10)......$$ (Eq.1)

Where:

E$_v$: Daily evaporated volume, A: area of the cross-section of the column (268.80 cm^2), and 10: conversion factor from cm to mm.

The active layer of leaching water (ALL) was found using the equation:

$$ALL = [Print gross water\ (cm)] - [Hydraulic loading\ (cm)] + Evaporation\left(\frac{mm}{10}\right) + \pi cs...$$ (Eq.2)

Where:

Hydraulic load =10 cm, 10 is the conversion factor from mm to cm y πcs = pore volume of soil saturation in cm^3.

The quantification of salts extracted began when the first drop of the effluent was collected. In this respect, the volume of water with which this drop is collected is considered the value of the soil saturation capacity (Qπ). For researchers such as Safanov et al. and Sánchez et al., it is the leaching constant of any soil depth [20,10]. The collection of aqueous extracts continued until we obtained the volumes of leaching water $\frac{Q_a}{Q_\pi}$ = 1.5 and 3.0.The experimental leaching lasted 108 days (April 14 to August 22, 2010). After the pore volumes$\frac{Q_a}{Q_\pi}$ were obtained, the test tubes were removed and the water load was eliminated from each column. Later, the soil samples were taken in thicknesses of 5 cm to a total depth of 50 cm in each column. The samples were air dried and analyzed in the laboratory for determining their residual salinity levels, and physical and chemical properties. The results of the leaching course were graphed as curves for the leaching of salts extracted, and adjusted to an exponential mathematical prediction model $Y = Ax^b$.

A statistical correlation analysis was run to determine the degree of association between EC which variables leached soluble cations, anions, the SAR and the ESP of the aqueous extracts. Later, the average residual salinity of the soil columns of the different treatments were obtained and its standard deviation and variation coefficient were determined. Finally, statistical analysis was performed with *P* =.05 The data was analyzed using the Statistical Analysis System SAS [21].

3. RESULTS AND DISCUSSION

3.1 Physical and Chemical Characterization of Soils

These are intermediate-depth soils (1 to 1.2m), formed by the accumulation of sediments with a clay loam texture and crust of limestone derived from colluvial processes. According to the FAO/UNESCO classification system [14], the soils are vertisols. The grain size analysis gave an apparent density of 1.17 gcm^{-3}, as well as a low permeability and hydraulic conductivity ≈ 0.5cm h^{-1}, which can be explained by the reduction of pore space (≈ 35%) in the soil due to the predominance of clay particles. These soils have poor drainage and an unstable structure due to the processes of expansion and contraction under humid and dry conditions. Its argillic composition favors water adsorption, which, along with its poor hydraulic conductivity, induces waterlogging and anaerobic conditions in the rainy season, which affects growth and development of glycophytes [3]. They show a low organic matter content < 3% and a cationic exchange capacity of around 20mEq100g^{-1} of soil, hence their lower fertility. The brownish-yellow color of wet soil [19] indicates poor drainage.

3.1.1 Initial salinity of soils

The evaluation of initial salinity (I_s) 0-50 cm depth within the column for the three soil-water extraction ratios 1≈0.2-0.6, 1:5 and 1:10 gave an average EC values of 15.14, 4.56 and 5.09 dS m^{-1} respectively, equivalent to saline concentrations of 9.68, 2.91 and 3.26g L^{-1}. This indicates that EC values decreased with a higher extraction ratios (Table 1). The behavior of the EC is inconsistent with the saline concentration obtained in the dry residue calcined (DRC) of each ratio, since this concentration increased as the extraction ratio increased. This can be explained by the different water solubilization capacity of each ratio. Namely a greater volume of water passing n times through a soil thickness, increases not only solubilization but the amount of extracted salts [10]. For an adequate evaluation of the initial

reserve of salts in the soil, the parameter EC is not adequate, since it is an indirect form of measuring the salt concentration subjected to different ratios of soil-water extractions, and therefore it undervalues the real salinity. In this regard, Teterin believes that in determining I_s, it is preferable to quantify this salt reserve based on concentration values determined by the ratio $\frac{Saltsweight(g)}{100\ g\,of\,soil}$ [22]. In this sense, the values of I_s determined in the DRC for the ratios 1≈0.2-0.6, 1:5 and 1:10 were, on average, 1.07g of salts 100 g^{-1}of soil, 2.43 g of salts 100 g^{-1} of soil, and 3.20 g of salts 100 g^{-1} of soil, equal to initial salinities per surface unit of 69.03 Mg ha^{-1}, 153.95 Mg ha^{-1} and 201.37 Mg ha^{-1}, respectively. The variance analysis with *P*=.05 indicates that the extraction ratio 1:10 gave a significantly higher $I_s$than that for ratios 1:5 and 1≈0.2-0.6. Likewise, the ratio 1:5 is significantly higher to the ratio 1≈0.2-0.6. These initial salinity values were a reference to quantify the salts extracted in the leaching process.

The salinization of this soil thickness is a result of the interaction of the arid conditions (excessive evaporation and scarce rainfall), poor natural drainage and the rise of phreatic waters due to capillarity, as well as of irrigation with deep well water with EC > 2000µS cm^{-1} [23]. Its reaction was alkaline with pH values in the interval 6.5 to 8.0, SAR in an interval 10.0 to 14.0 and ESP in the interval 10% to 15%, which corresponded to values obtained in the soil-water extraction ratios 1≈0.2-0.6, 1:5 and 1:10 (Table 1). Therefore, these soils are prone to sodicity. The salt level higher than EC > 4.0dS m^{-1} exceeds the tolerance threshold considered critical by Maas [24] for various crops as practiced in the study area, which constitutes an adverse abiotic factor for the productivity of the agroecosystems in the zone. In sum, these vertisols have a saline-sodicitytypogenesis, in transition towards solonchaks, and therefore their use and management in irrigation agriculture should consider selecting crops tolerants to salts and the application of hydrochemical methods, supported by the lixiviation of salts.

3.1.2 Chemical quality of the deep wells water

The chemical analysis of the water samples collected (Table 2), shows its sulphatic-magnesic composition, with a neutral pH (7.1 to 7.3), high salinity (EC ≈ 4000 to 6000µS cm^{-1}) and a moderate sodicity (SAR ≈ 3.0), giving type C4S1 water (saline with low sodicity). Therefore, according to Ayers and Westcot [25], they can be used for irrigating salt-tolerant crops. However, higher sodium and SAR in irrigation water may be injurious to plant growth through soil structural deterioration, water infiltration rate reduction and hydraulic conductivity [26]. Basically, these waters have high soluble salt. Calculate the soluble salt contents of these waters to support this statement.

3.3 Salt Leaching Process

It is worth noting that in this study, treatment I tested at saturation capacity in columns one, two, and three (pore volume $\frac{Q_a}{Q_\pi}$= 0), there was no salt extraction, although there was a vertical descending displacement of salts, from the higher to the lower thicknesses of the columns, as it noted by the results of residual salinity (R_s).

Table 1. Initial salinity, sodicity and soluble ions from aqueous extracts from soil profile saturation pastes analyzed in the extraction ratios 1≈0.2-0.6, 1:5 and 1:10

Profilenum	Soil-water ratio	pH	€EC (dS m⁻¹)	§mEq 100 g⁻¹ of soil									†DRC g L⁻¹	¶SAR (mmol$_c$ L⁻¹)$^{1/2}$	‡ESP
				HCO$_3$⁻¹	Cl⁻	SO$_4$⁻²	Sum	Ca²⁺	Mg²⁺	Na⁺	K⁺	Sum			
1	1≈0.2-0.6	8.3	16.51	0.19	4.06	8.42	12.67	1.03	9.32	3.17	0.35	13.87	1.06 C	10.66	12.26
1	1:5	6.2	4.72	0.50	5.18	25.25	30.93	13.33	12.70	4.71	0.56	31.30	2.36 B	7.88	9.38
1	1:10	6.5	5.00	1.06	8.60	39.55	49.21	27.13	17.06	5.46	0.75	50.40	3.09 A*	8.88	10.58
2	1≈0.2-0.6	8.0	18.00	0.12	3.82	8.32	12.26	1.61	9.00	2.07	0.47	13.15	1.10 C	6.87	8.15
2	1:5	6.7	4.47	0.40	6.66	24.61	31.67	15.20	10.10	5.32	0.75	31.37	2.55 B	11.44	13.50
2	1:10	6.4	5.19	1.55	9.19	34.28	45.02	20.32	16.03	7.65	0.83	44.83	3.15 A*	13.73	15.96
3	1≈0.2-0.6	8.1	17.60	0.14	3.15	7.73	11.02	1.21	7.84	3.36	0.06	12.47	1.07 C	11.36	13.41
3	1:5	6.5	4.35	0.30	5.41	26.30	32.01	14.28	11.62	5.68	0.71	32.29	2.40 B	12.06	14.18
3	1:10	6.6	5.10	1.40	9.30	35.04	45.74	23.03	16.77	6.35	0.67	46.82	3.37 A*	10.89	12.89

(Where: € EC = Electrical conductivity; §mEq = milliequivalents per liter; †DRC = Dry Residue Calcined; ¶SAR = Sodium Adsorption Ratio; ESP = Exchangeable Sodium Percentage). A, B, C = Test of averages between soil-water extraction ratios for the variable I$_s$ evaluated in CDR. Pr F < 0.0001. Note: Averages with the same letter are not significantly different.* Statistical significance

Table 2. Chemical and physical characterization of the irrigation waters in the area of study

Sample Identification	pH	EC µS cm⁻¹	§Ψπ MPa	†mEq L⁻¹									¶SAR (mmol$_c$ L⁻¹)$^{1/2}$
				HCO$_3$⁻	Cl⁻	SO$_4$⁻²	Sum	Ca²⁺	Mg²⁺	Na⁺	K⁺	Sum	
Well Water 1. Ejido "Tablas"	7.1	6240	-0.22	2.50	49.50	49.86	101.86	25.70	60.80	17.10	1.26	104.86	3.67
Well Water 2. Ejido "Tablas"	7.2	6230	-0.22	2.50	49.25	52.23	103.98	25.60	60.40	17.30	1.30	104.60	3.73
Well Water 3. Agricultural Colony "La Morita"	7.3	4830	-0.28	3.00	37.25	33.22	73.47	27.90	32.10	13.10	0.57	73.67	3.38
Well Water 4. Ejido "Palomas"	7.2	3230	-0.11	3.40	17.50	30.35	51.25	27.60	17.40	5.30	0.33	50.63	1.58

(Where: § ψπ (MPa) = osmotic potential (Mega Pascal); †mEq L⁻¹ = milliequivalents per liter; ¶ Sodium Adsorption Ratio (mmol$_c$L⁻¹)$^{1/2}$ = charge millimol per liter)

The amount of leachate for the soil water ratios 1≈0.2-0.6, 1:5 and 1:10, had the tendency to leach more salts from the columns when increasing the volume of water applied. The values of I_s obtained in the test are a reflection of this behavior, and their projection at field level shows the same trend. Data obtained for I_s showed that the lowest saline extraction was obtained at the 1≈0.2-0.6, and the greatest saline extraction was recorded at the ratio 1:10. According to Kovda (7) saline waters used for leaching exhibit such regularity of displacement. However one must consider that the use of distilled water (lacking electrolytes), imposes limitations to leaching as this decreases pore volume and clog the soil because of colloidal clay dispersion caused by effect of Na^+ on the soil exchange complex. Perhaps this difference is due to a greater volume of water with low salt concentration has a greater potential to solubilize and displace salts [27]. Fig. 2 shows that with a pore volume $\left(\frac{Q_a}{Q_\pi} = 1.5\right)$ and a volume at saturation capacity Qπ=1971.72m³ ha⁻¹, the course of the leaching is different for each extraction ratio. In this way, in the ratio 1≈0.2-0.6, the extraction rate that results from dividing the terms $\frac{I_s' - \sum S_{ext}}{I_s'} * 100$ gave negative values from a $\frac{Q_a}{Q_\pi} = 0.44$ for effluent number 23, where a value of -0.98% of salts extracted was obtained. In the exponential graphs, these negative values were considered near to 0%, and indicate that the extraction reached a limit value, induced by insufficient water to solubilize and displace salts, linked to the undervaluation of the I_s. Researchers such as Volobuyev and Sánchez et al. [28,10], consider this undervaluation as a disadvantage of the saturation capacity ratio in the analysis of a leaching process, since it allows for the quantification of salts where there are still salts to be extracted. This is not true of the soil-water extraction ratios 1:5 y 1:10, since the same $\frac{Q_a}{Q_\pi} = 0.44$, in the effluent number 23, the ratio 1:5 gave a reserve of extracted salts of 54.61%, whereas ratio 1:10 gave 65.38% of salts leached. The difference in percentages persist up to effluent number 80 after the active volume of leaching water established entered the columns. In this effluent, we obtained a reserve of extracted salts of 36.57% for ratio 1:5 and 51.62% for the ratio 1:10. This indicates that the latter extraction ratio gave a greater reserve of extracted salts, including salts with high, intermediate, and low solubility. This ratio uses a greater volume of water than ratio 1:5. In this regard it should be noted that the purpose of a leaching process is to displace the most soluble salts from a specific soil thickness with a lower water. For this reason the ratio 1:5 is widely used to quantify salts extracted in most soil science laboratories in the world. González et al. consider that the ratio 1:5 is adequate for determining a large amount of easily soluble salts [9]. However, to Safanov et al., the ratio 1:10 is adequate for the evaluation of salt reserves in sulphatic saline soils, since it not only determines soluble salts, but also helps monitor the displacement of salts with an intermediate solubility of a specific soil thickness, and thus evaluate more accurately the real amount of salts in the soil [20].
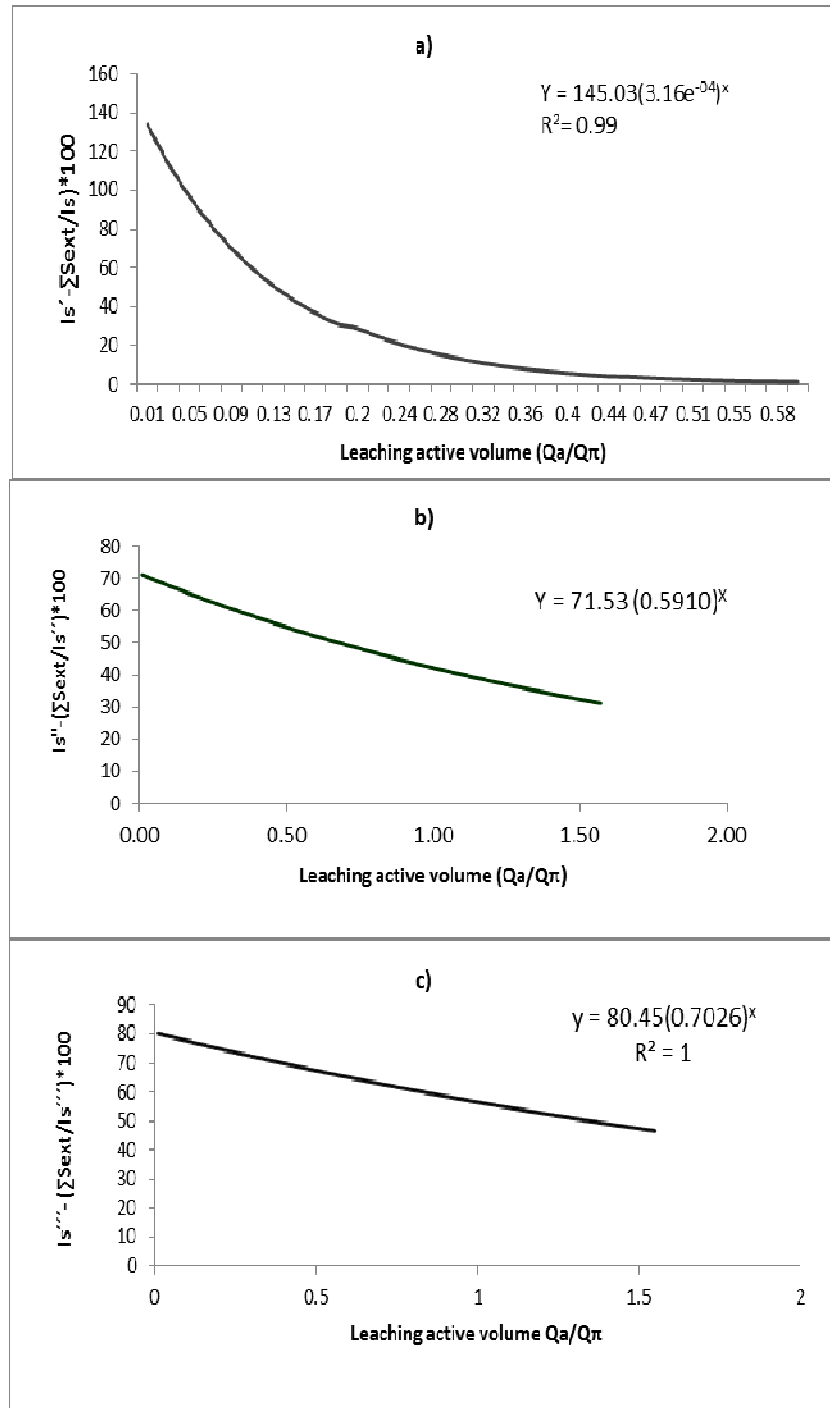
Fig. 2. Average course of salt leaching (columns 4, 5, and 6), based on a $\frac{Q_a}{Q_\pi} = 1.5$. Soil-water extraction ratio: a) 1≈0.2-0.6, b) 1:5 and c) 1:10
Where: Is´= 69.03 Mg ha⁻¹; Is´´ = 153.59Mg ha⁻¹; Is´´´= 201.37Mg ha⁻¹. Qπ= 1971.72m³ ha⁻¹

A similar behavior was found when evaluating the percentage of reserve salts extracted by the three soil-water extraction ratios based on the $\frac{Q_a}{Q_\pi} = 3.0$and a volume at saturation capacity of Qπ = 2328.12 m^3 ha^{-1}, with the difference that the percent salt extracted with regard to I$_s$ is higher in the different effluent than those recorded in $\frac{Q_a}{Q_\pi} = 1.5$ (Fig. 3). For example with this active volume of leaching water eighty extracts were obtained, while in the $\frac{Q_a}{Q_\pi} = 3.0,$ one hundred and seventy-six effluents were obtained, implying greater amount of leached salts. Under these conditions, the ratio 1:5 gave a reserve of extracted salts of 25.88%, whereas in the ratio 1:10 the percentage of extracted salts was 43.46%. This difference indicates that a higher fraction of leaching water with a low salt concentration is related to a higher amount of displaced salts. Also it can be seen that with increasing in active volume of leaching water, more salts were extracted in the first effluent collected, while the salt concentration dropped progressively in the last effluents.

For example, in an average of three columns, the amount of salts extracted in the first effluent with volumes $\left(\frac{Q_a}{Q_\pi} = 1.5 \ y \ 3.0\right)$ were 141.70 g L^{-1} and 157.50 g L^{-1}, respectively. As the proceeded salt concentration dropped progressively up to the last effluent collected, in which these treatments displayed values of 4.40g L^{-1} in effluent number 88 and 3.42 g L^{-1} in effluent number 176. This behavior is a universal regularity of the leaching process and can be explained by the solvent effect of the experimental water, since the water used in the trial was distilled (low electrolytic level), which is why, at the beginning of the experiment, the first effluents extracted a large amount of salts. However, as the leaching moved on in its descending course, the solvent capacity of the water fell and extracted less and less salts in the later effluents. Similar observations were made by Sánchez et al. [10], who point out that at the beginning of the leaching course, the low salinity waters have a greater capacity to charge with ions, yet as time goes by, they displace less and less salts, because their reconcentration induces a lower dissolution of solutes. In this sense, Hopkins and Ayers and Westcot, indicate that waters with lower salt concentration have a greater activity and chemical potential to solubilize salts than those that have a higher concentration of solutes and therefore reduce their chemical potential and solvent activity [29,25]. An example of the chemical evolution of leaching water as contained in Table 3, related to the ionic composition of column effluent in which a leaching volume $\frac{Q_a}{Q_\pi} = 1.5$ was applied. In this table can be notice that the effluents were loaded with a large amount of ions in the order Mg^{2+} > Na$^+$ and SO$_4^{-2}$>Cl$^-$, and to a lesser extent, with ions Ca^{2+}, K$^+$ and HCO$_3^-$. The association between EC of the aqueous extracts and the leached ions in each treatment gave a higher correlation between EC and Mg^{2+} (r=0.99), EC and Na$^+$ (r= 0.94), EC and SO$_4^{-2}$ (r=0.99). We can deduce from this correlation that during the leaching process, the concentration of Mg^{2+}, Na$^+$ and SO$_4^{-2}$ had a wider relation with the EC values of the extracts, and that as the leaching progressed, the removal of these ions diminished. Consequently, there was a reduction in the EC values until the end of the process. An intermediate correlation was established between EC and Cl^{-1} (r = 0.53), and between EC and HCO$_3^-$ (r = 0.55). These anions tend to form NaCl, MgCl$_2$, Mg(HCO$_3$)$_2$ and NaHCO$_3$ salt, which occur constantly in sulphatic soils. Meanwhile, the correlation between EC and Ca^{2+} was 0.11, indicating that this ion was evacuated at lower concentrations in the aqueous extracts and precipitates as Ca(HCO$_3$)$_2$, a low-solubility salt.
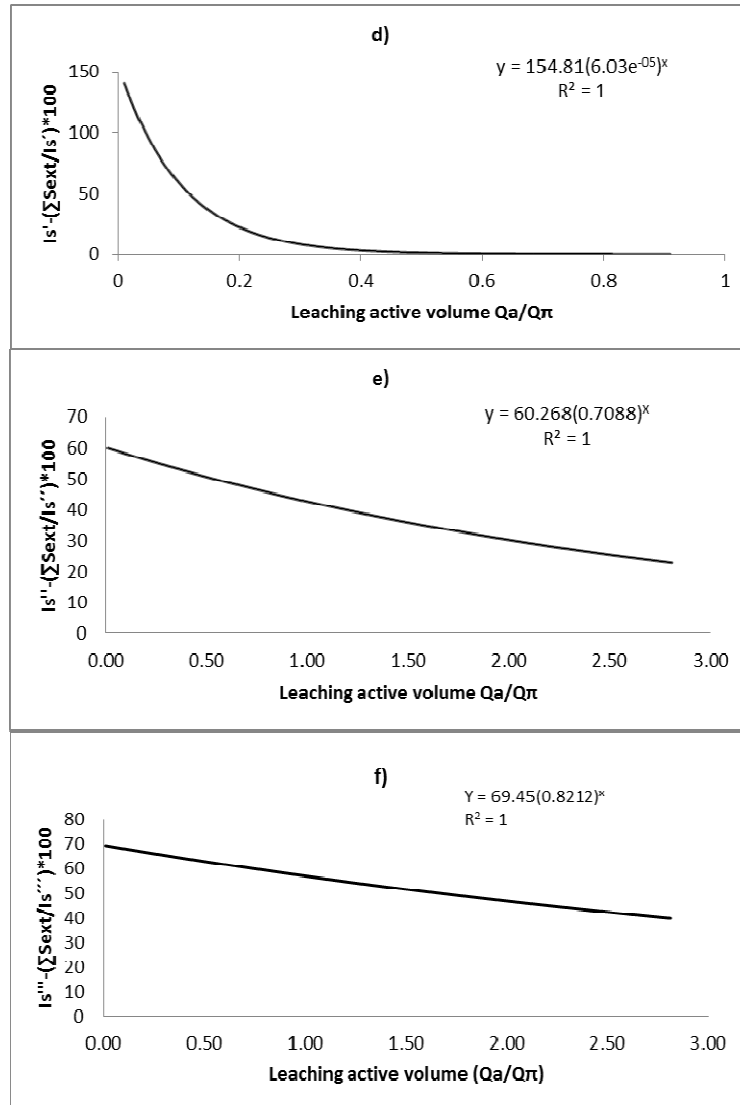
Fig. 3. Average course of salt leaching (columns 7, 8 and 9), based on $\frac{Q_a}{Q_\pi} = 3.0$. Soil-water extraction ratio: d) 1≈0.2-0.6, e) 1:5 and f) 1:10

Where: Is´= 69.03 Mg ha^{-1}; Is´´ = 153.59 Mg ha^{-1}; Is´´´= 201.37 Mg ha^{-1}. Qπ= 2276.78 m^3 ha^{-1})

The chemical interaction of the predominant ions led to a tendency to form the salts $MgSO_4$> $NaSO_4$>$MgCl_2$ >$NaCl$. The high solubilities of these salts (275g L^{-1}, 280g L^{-1}, 353g L^{-1} and 264 g L^{-1} respectively), are the reason why they were more leached from the soil columns, in comparison to low solubility salts such as $Ca(HCO_3)_2$, $Mg(HCO_3)_2$ (0.013g L^{-1}) and Ca_2SO_4 (1.9g L^{-1}), which precipitate at intermediate and low thicknesses due to their low solubilities that prevent their leaching. Lower the removal of HCO_3^- ions is due to their solubility decreased under conditions of high salt concentrations of the soil solution (>5g L^{-1}).

Table 3. Salinity and ionic composition of leaching waters. Extraction ratio 1:5. $\frac{Q_a}{Q_\pi} = 1.5$

No. Effluent	pH	EC (dS m^{-1})	CATIONS (mEQ L$_{-1}$)				TOTAL	ANIONS (mEQ L$_{-1}$)			TOTAL	DRC (g L^{-1})	Ψπ MPa	SAR (mmol$_c$ L^{-1})$^{1/2}$	ESP
			Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$		HCO$_3^-$	Cl$^-$	SO$_4^{-2}$					
1	6.4	105.00	38.00	1642.00	592.00	52.50	2324.50	9.60	767.25	1625.03	2401.88	141.70	-6.75	28.56	41.28
2	6.6	94.00	26.40	1413.60	543.00	50.90	2033.90	16.65	625.50	1461.33	2103.48	119.70	-6.26	28.35	40.97
3	6.4	85.00	22.80	1287.20	555.00	53.30	1918.30	10.70	546.75	1428.89	1986.34	107.00	-4.83	30.40	44.02
4	6.2	84.00	21.20	1198.80	515.00	50.40	1785.40	10.20	513.00	1325.13	1848.33	106.80	-4.76	29.23	42.28
5	6.1	80.00	22.10	1197.90	481.00	46.80	1747.80	12.60	481.50	1285.70	1747.80	100.70	-4.64	27.29	39.39
6	6.2	79.00	17.00	1173.00	477.00	45.40	1712.40	11.75	459.00	1303.73	1774.48	103.20	-4.30	27.45	39.63
7	6.7	74.00	16.45	1083.50	437.00	42.80	1579.70	15.40	411.75	1210.77	1637.32	90.20	-3.87	26.15	37.69
8	6.9	70.00	20.60	999.40	440.00	43.70	1503.70	15.40	387.00	1156.36	1558.76	86.40	-3.57	27.27	39.36
9	7.0	68.00	22.85	987.100	515.00	51.90	1576.80	17.40	369.00	1190.40	1576.80	84.40	-3.54	32.05	46.47
10	7.1	66.00	23.00	954.40	311.00	32.10	1313.10	21.30	351.00	978.12	1359.42	81.10	-3.47	19.66	28.02
11	6.8	62.00	25.00	875.00	347.00	35.90	1282.90	23.10	319.50	987.31	1329.91	74.50	-3.13	22.81	32.72
12	6.9	59.00	22.00	818.00	327.00	34.10	1201.10	24.50	297.00	923.58	1245.00	71.00	-2.89	22.27	31.91
13	7.3	56.00	18.10	791.90	300.00	31.30	1141.30	24.50	274.50	884.41	1183.41	67.40	-2.67	20.85	29.78
14	7.2	54.00	18.30	751.70	294.00	30.30	1094.30	25.00	257.00	858.16	1135.16	65.50	-2.58	20.94	29.92
15	7.8	51.00	22.90	717.10	284.00	29.40	1053.40	20.65	238.50	823.67	1092.62	61.80	-2.55	20.56	29.36
16	7.8	49.50	21.20	688.80	280.00	29.50	1019.50	24.55	225.00	808.44	1057.99	57.20	-2.34	20.70	29.57
17	7.4	49.50	22.80	647.20	273.00	29.10	972.10	26.35	223.87	757.97	1008.19	61.10	-2.40	20.74	29.63
18	7.2	52.00	20.20	719.80	297.00	31.10	1068.10	27.85	225.00	856.01	1108.86	64.20	-2.46	21.54	30.82
19	7.5	47.00	20.20	719.80	245.00	25.60	1016.60	25.90	204.75	818.94	1049.59	57.20	-2.25	17.77	25.20
20	7.6	45.90	18.90	731.10	245.00	25.60	1020.60	25.25	195.75	839.58	1060.58	52.00	-2.19	17.67	25.05
21	7.8	44.00	22.00	718.00	235.00	24.60	999.60	21.25	183.37	823.17	1038.79	49.70	-2.01	17.02	24.09
22	7.6	42.00	18.50	611.50	236.00	24.80	890.80	26.00	172.12	727.31	925.43	48.10	-1.97	18.53	26.33
23	7.7	41.90	19.00	601.00	215.00	23.00	858.00	24.50	163.12	703.89	891.51	46.00	-1.88	17.01	24.06
24	7.7	36.50	20.50	509.50	188.00	20.80	738.80	24.00	135.00	608.79	707.79	41.80	-1.67	16.02	22.60
25	7.6	36.00	20.50	509.50	189.00	21.60	740.60	24.00	132.75	613.04	706.79	41.20	-1.68	16.11	22.72

26	7.6	35.50	20.00	500.00	188.00	21.90	729.90	18.75	129.37	610.86	758.98	39.80	-1.74	16.18	22.83
27	7.9	33.10	18.00	472.00	170.00	20.20	680.20	28.25	114.75	564.06	707.06	36.70	-1.46	15.08	21.20
28	7.9	30.50	20.00	400.00	156.00	18.70	594.70	22.00	105.75	490.29	618.04	33.30	-1.30	14.87	20.88
29	7.9	28.00	18.00	382.00	134.00	16.40	550.40	21.50	81.00	470.29	572.79	30.60	-1.20	13.10	18.25
30	7.8	26.00	19.00	351.00	125.00	15.70	510.70	19.00	76.50	435.96	531.46	28.80	-1.11	12.67	17.61
31	7.8	23.50	17.50	312.50	107.00	14.30	451.30	18.50	65.25	385.92	469.67	22.50	-1.00	11.47	15.82
32	7.7	22.40	18.00	292.00	108.60	16.35	433.90	18.25	58.50	375.00	451.75	22.20	-0.95	11.99	16.59
33	7.4	22.50	18.00	292.00	112.50	15.35	438.60	18.00	56.25	364.55	438.80	21.60	-0.93	12.42	17.23
34	7.7	21.40	17.50	272.50	100.00	14.95	404.90	17.75	54.00	349.80	421.55	23.90	-0.87	11.40	15.71
35	7.4	21.40	17.00	273.00	97.40	14.75	402.15	18.00	49.50	351.38	418.88	19.90	-0.88	11.11	15.29
36	7.5	19.60	16.00	244.00	88.60	13.44	360.04	17.75	45.00	312.15	374.90	18.40	-0.78	10.66	14.61
37	7.6	18.30	17.00	243.00	79.10	12.67	351.77	16.25	38.25	312.13	366.63	17.00	-0.72	9.50	12.88
38	7.4	17.10	16.50	213.50	70.70	11.67	312.37	15.00	32.62	277.98	325.60	15.90	-0.68	9.00	12.14
39	7.3	15.80	17.00	203.00	62.60	11.18	293.78	15.00	29.25	262.10	306.35	14.80	-0.64	8.13	10.84
40	7.6	14.80	18.00	182.00	54.10	10.87	264.97	11.50	22.50	242.51	276.51	17.30	-0.57	7.32	9.64
41	7.7	14.80	17.50	182.50	52.30	10.96	263.20	14.50	22.50	226.20	263.20	17.00	-0.57	7.09	9.29
42	7.7	14.90	18.50	201.50	52.50	11.12	283.60	19.00	21.37	255.39	295.76	13.90	-0.57	6.79	8.85
43	7.4	13.60	18.50	181.50	46.10	10.14	256.20	14.00	20.25	233.04	267.29	12.90	-0.52	6.23	8.01
44	7.4	12.40	18.50	161.50	39.70	9.32	229.02	13.50	16.20	209.28	238.98	15.30	-0.54	5.63	7.12
45	7.3	11.70	18.00	162.00	35.60	8.90	224.50	13.00	9.90	211.68	234.58	11.10	-0.47	5.05	6.26

Table 3 Continued.........

No. Effluent	pH	EC (dS m⁻¹)	CATIONS (MEQ L-1)				TOTAL	Anions(MEQ L-1)			TOTAL	DRC (g L⁻¹)	Ψπ MPa	RAS (mmol$_c$ L⁻¹)¹ᐟ²	ESP
			Ca²⁺	Mg²⁺	Na⁺	K⁺		HCO₃⁻	Cl⁻	SO₄⁻²					
46	7.6	10.60	19.50	140.50	27.10	7.59	194.60	12.00	10.35	180.86	203.21	9.90	-0.43	4.04	4.75
47	7.7	9.60	19.50	130.50	24.10	8.13	182.23	11.00	7.20	172.23	190.43	12.70	-0.38	3.70	4.24
48	7.7	9.40	22.00	118.00	22.30	8.29	170.59	11.50	7.20	159.48	178.18	12.50	-0.37	3.50	3.94
49	7.8	9.50	23.50	118.50	21.90	8.51	170.41	11.50	5.85	160.71	178.06	9.00	-0.34	3.40	3.79
50	7.7	8.70	20.50	108.50	17.70	7.58	155.28	10.75	5.40	146.08	162.23	8.10	-0.29	2.89	3.04
51	7.9	8.10	20.00	102.50	14.70	7.04	144.24	10.75	4.05	135.91	150.71	7.60	-0.29	2.46	2.39
52	7.8	7.60	20.00	92.50	12.20	6.71	131.41	10.75	3.15	123.38	137.28	10.50	-0.27	2.11	1.88
53	7.9	7.10	21.50	86.00	10.10	6.43	124.03	10.00	2.38	117.23	129.61	10.30	-0.23	1.77	1.37
54	8.0	6.70	21.50	73.50	7.80	6.37	109.17	9.50	2.34	102.19	114.03	6.20	-0.20	1.44	0.88
55	8.0	6.90	21.50	81.00	7.80	6.72	117.02	9.50	1.84	110.96	122.30	6.40	-0.22	1.40	0.81
56	7.8	6.80	22.00	83.00	7.10	6.58	118.68	9.50	1.71	107.47	118.68	6.30	-0.22	1.26	0.60
57	7.8	6.70	22.00	78.00	6.30	6.36	112.66	9.50	2.16	106.05	117.71	6.10	-0.19	1.14	0.42
58	8.0	6.40	22.00	75.50	5.10	5.83	108.43	9.50	0.54	103.30	113.34	5.80	-0.17	0.93	0.11
59	8.0	6.20	21.00	71.50	4.50	5.63	102.63	7.75	1.21	98.35	107.31	5.70	-0.15	0.84	0.00
60	8.1	6.00	20.50	72.00	3.70	5.52	101.72	7.50	1.17	97.70	106.37	9.20	-0.21	0.69	0.00
61	8.1	5.90	21.00	69.00	3.30	5.77	99.07	7.00	0.99	95.63	103.62	5.30	-0.14	0.62	0.00
62	8.0	6.00	21.50	68.50	3.20	5.93	99.13	8.75	0.90	93.95	103.60	5.50	-0.20	0.60	0.00
63	8.1	6.30	23.00	72.00	3.40	6.17	104.57	8.00	0.90	100.45	109.35	5.70	-0.35	0.62	0.00
64	8.0	5.90	21.50	71.00	2.80	5.43	100.73	8.92	0.82	95.53	105.27	5.30	-0.19	0.52	0.00
65	7.9	5.80	22.00	65.50	2.50	5.15	95.15	9.92	0.68	88.77	99.37	5.20	-0.19	0.47	0.00
66	8.0	5.80	21.00	66.50	2.10	4.89	94.49	6.02	0.82	92.03	98.87	5.10	-0.18	0.40	0.00
67	7.8	5.60	22.00	60.50	1.90	4.67	89.27	6.80	0.82	85.73	93.35	4.90	-0.22	0.37	0.00

68	7.9	5.60	22.50	60.00	1.90	5.25	89.65	8.40	0.64	84.64	93.68	5.10	-0.19	0.37	0.00
69	7.9	5.50	23.00	67.00	1.90	5.22	97.12	8.00	0.63	92.91	101.54	5.30	-0.20	0.35	0.00
70	8.0	5.57	23.00	62.00	1.70	4.97	91.67	8.58	0.63	86.58	95.79	5.10	-0.20	0.32	0.00
71	8.1	5.50	23.00	59.50	1.50	4.51	88.51	7.94	0.72	83.64	92.50	4.90	-0.19	0.29	0.00
72	8.1	5.50	22.00	63.00	1.40	4.35	90.75	7.66	0.72	86.48	94.86	4.80	-0.22	0.27	0.00
73	8.1	5.40	21.50	61.00	1.20	4.28	87.98	6.80	0.72	84.48	92.00	4.70	-0.21	0.23	0.00
74	8.1	5.50	22.00	60.50	1.20	4.50	88.20	8.86	0.57	82.70	92.13	4.80	-0.20	0.23	0.00
75	8.1	5.70	22.50	60.00	1.30	4.67	88.47	6.92	0.57	85.02	92.51	5.00	-0.19	0.25	0.00
76	8.1	5.50	23.00	64.50	1.20	4.39	93.00	7.88	0.57	88.87	97.32	5.00	-0.18	0.22	0.00
77	8.1	5.30	22.50	57.50	1.10	4.08	85.18	7.40	0.39	81.25	89.07	4.70	-0.18	0.21	0.00
78	8.1	5.30	22.50	60.00	1.10	4.00	87.60	7.70	0.43	83.44	91.57	4.70	-0.18	0.21	0.00
79	8.2	5.30	22.50	57.50	1.00	3.83	84.83	8.04	0.68	79.91	88.63	4.60	-0.18	0.19	0.00
80	8.2	5.20	22.50	57.50	0.80	3.97	84.77	7.40	0.72	80.84	88.60	4.60	-0.20	0.15	0.00
81	8.2	5.40	22.00	60.50	1.00	4.12	87.62	7.24	0.72	83.64	91.60	4.80	-0.22	0.19	0.00
82	8.3	5.40	22.50	60.00	0.80	3.94	87.24	8.36	0.64	82.15	91.15	4.70	-0.22	0.15	0.00
83	8.2	5.40	23.00	57.00	0.80	3.65	84.45	8.88	0.90	78.40	88.18	4.70	-0.21	0.15	0.00
84	8.1	5.30	22.50	62.50	0.70	3.44	89.14	7.88	0.91	79.44	88.23	4.70	-0.19	0.13	0.00
85	8.1	5.10	23.00	57.00	0.70	3.34	84.04	7.88	0.68	79.25	87.81	4.70	-0.19	0.13	0.00
86	8.4	5.10	23.00	52.00	0.70	3.50	79.20	7.20	0.72	74.84	82.76	4.20	-0.19	0.14	0.00
87	8.1	5.40	23.00	57.00	0.70	3.50	84.20	7.76	0.90	79.31	87.97	4.50	-0.19	0.13	0.00
88	8.0	5.30	23.50	54.00	0.70	3.34	81.54	8.48	0.84	76.04	85.16	4.40	-0.19	0.13	0.00

The higher the formation of $Ca(HCO_3)_2$ salt, the lower the amount of HCO_3^- ionspassing the first extractans. In contrast, when the salt concentration lowered in the last effluents, a greater solubilization and evacuation of $NaHCO_3$ was produced, which explains the slight increase in HCO_3^- ions in those effluents. This also explains the change in pH from slightly acid in the first extracts, to alkaline in the last, since this parameter fluctuated in an interval from 6.4 to 8.2. This change in pH indicates that the leaching extractans were loaded with sodium [3]. The observation corroborates with the remarks by Volobuyeb and Litovchencko, who argue that in a leaching process, the easily soluble salts are leached more intensely, unlike the low-solubility salts that are displaced less [12,28]. According to Szabolcs, Mg^{2+}, Na^+ and Cl^-ions have, by nature, a high geochemical mobility, induced by their ionic radius, hydration radius, energetic coefficient and valence, which altogether influence their capacity to migrate and accumulate in soils to form $MgSO_4$, Na_2SO_4 and $NaCl$ salts [30].

These salts under conditions of saturation and high concentration cause the precipitation of $Ca(HCO_3)_2$ and Ca_2SO_4, which explains the mobility of these during the leaching process, since they remain in solution and in the lowest removal of Ca^{2+} in the extracts.

Na_2SO_4 has a determining chemical influence on the studied soils, since its interaction with $CaCl_2$ favors the solubilization of $NaCl$ and $MgSO_4$, and the precipitation of $CaSO_4$. On the other hand, a high concentration of $NaCl$ and $MgSO_4$ in the solution produces the solubilization of $CaSO_4$ and the formation of Na_2SO_4 and $CaCl_2$. This explains the presence in the leaching effluents of large amounts of $MgSO_4 > Na_2SO_4 > NaCl$. The predominance of sulphatic salts over hydrochloric salts is typical of soils affected by sulphatic salts, which according to Arinushkina quoted by Kovda [7] is characterized by a predominance of sulfate ions over chlorine ions, a statement that agrees with the data obtained in this study. It was also evident that Na_2SO_4 intensely reduced its osmotic effect as the process evolved (Table 4), and we can therefore state that the leaching of this salt reduces the risk of physiological drought in plants. The leaching also produced the displacement of large amount of $MgSO_4$ and $NaCl$ outside the rhizosphere. This desalination can be used by producers to better manage the soil by applying agricultural gypsum to improve soil structure and consequently, permeability and hydraulic conductivity and thereby attenuate the salt effects.

During the leaching process a lot of Mg^{2+}, Na^+, Cl^- and SO_4^{-2} ions were extracted forming $MgSO_4$, $NaCl$, $MgCl_2$ and Na_2SO_4 salt. At the end of the process Na^+ and Cl^- ions left to move to the extracts, which confirms they were displaced from the soil columns subjected to the $\frac{Q_a}{Q_\pi} = 1.5 \; and \; 3.0$ leaching water. The values of SAR and ESP effluent closely related to the movement of Na^+ and Mg^{2+}, since high SAR values indicate that both ions were evacuated in large quantities in the first effluent. While low SAR values coincide with low concentrations of these cations, which occurred in the effluent collected at the end. This is a positive effect of the course of leaching because the displacement of both ions (high geochemical mobility) have pronounced effects on the flocculation of colloidal systems of soils, as indicated by Can et al. and Sharma et al. [31,32]. The rest of the ions were removed, although in lower amounts, and this tendency continued throughout the process. At the end of the course of leaching, the saline extraction curves for each leaching norm became stable, without reaching a level of complete salt removal. That is, despite the increase in the leaching fraction, there are always salts in the soil that need extraction (Figs. 2 and 3). Volobuyev [28] indicated that the ratio 1≈0.2-0.6 has a limit of displacement and salt extraction derived from a lower layer of water, which explains why after a certain number of effluents, the salt extraction stopped. The opposite is true in the case of the soil-water extraction ratios 1:5 and 1:10, which, at a greater active leaching intensity, produce a greater

number of effluents, and therefore evacuate a greater amount of salts. However, the volume of leaching water becomes a restrictive factor to keep pace with the displacement of salts until a level of complete removal, because, in essence, these are a constituent of the soil genesis [33].

3.3 Residual Salinity

The analysis of residual salinity (R_s) in the soil columns subjected to the different active volumes of leaching water indicates an intense desalinizing effect on the higher thicknesses, which decreased gradually in the lower ones, where the salts build up. Specifically, in the thickness 0-30 cm, leaching with an active volume $\frac{Q_a}{Q_\pi} = 3.0$ a significant difference was obtained, as the residual salinity decreased to values of 0.12 g of salts 100 g^{-1} of soil, 0.89 g of salts 100 g^{-1} of soil, and 1.68 g of salts 100 g^{-1} of soil, for each extraction ratio. While the residual values of 40-50 cm thickness increased to the concentrations of 0.15 g of salts 100 g^{-1} of soil, 0.94 g of salts 100 g^{-1}of soil, and 1.79 g of salts100 g^{-1} of soil, in each extraction ratio. Desalinization is evident considering the initial salinity (I_s) values reported in Table 1. The highest values of $I_s$and salts extracted correspond to the lowest values of R_s in the soil columns evaluated in ratios 1:5 and 1:10. Therefore the salient treatments were identified by the intensity of saline extraction. Under field conditions I_s projection showed values of 69.03 Mg ha^{-1}, 153.59Mg ha^{-1} and 201.37 Mg ha^{-1} in each ratio, while the R_s at 0-30 cm thickness showed values of 11.07Mg ha^{-1}, 69.99 Mg ha^{-1} and 109.48Mg ha^{-1}, which implies displacement of 57.96 Mg ha^{-1}, 83.60 Mg ha^{-1} and 91.89 Mg ha^{-1} of salts. The study indicates that the determination of the salt reserve in the soils depends on the soil-water extraction ratio used. Given the amount of salts extracted, ratios 1:5 and 1:10 must be considered as an adequate option to evaluate the leaching of soluble and intermediately soluble salts in the sulphatic saline soils under study. A greater amount of $CaSO_4$ was determined in the ratio 1:10, which can be explained in the fact that a greater volume of leaching water increases this salt's solubility. Data also reveal that the potential salinity (PS) varies with the active volume of leaching water and the extraction ratio, since with a $\frac{Q_a}{Q_\pi}$=1.5 the ratio 1:5 gave lower values of PS, which indicates a low risk of potential salinity. However, with the ratio 1:10, values taken were higher, which, according to Coras [34], indicates a risk of potential salinity. This is related to the higher determination of residual salts in this ratio. Likewise, the leaching of sodic salts reduced the risk of sodification, since ESP values showed an absence of exchangeable sodium in all cases. Therefore this hydric technique must be considered as an alternative practice for soil improvement in the region. A more intense desalinizing effect was obtained when passing a greater volume of water on a specific soil thickness. Similar observations were made by Gili et al. [35]. The volume of leaching water calculated per surface unit for a $\frac{Q_a}{Q_\pi}$= 0 was of 2276.78 m^3 ha^{-1}, for a $\frac{Q_a}{Q_\pi}$= 1.5, it was 3296.72 m^3 ha^{-1}, whereas for a $\frac{Q_a}{Q_\pi}$= 3.0 it was 6830.34 m^3 ha^{-1}. According to Pizarro [36], these are water volumes used in very large leaching processes.

Table 4. Residual Salinity of the soil columns subjected to leaching

Treatment	Thickness (cm)	pH	EC (dS m^{-1})	R$_s$(g de sales/100 g de suelo)	PS (mmol$_c$ L^{-1})	ESP	Statisticalparameters			
							EC	R$_s$	PS	ESP
$\frac{Q_a}{Q_\pi} = 0$. Rel. 1≈0.2-0.6 A^1*B^2	(0-5]	7.4	2.42a	0.12a	0.00a	0a	m = 14.86	m = 0.74	m = 0.00	m = 0.25
	(5-10]	7.2	2.69a	0.13a	0.01a	0a	σ=21.92	σ = 1.08	σ = 0.00	σ=0.58
	(10-15]	7.3	3.11a	0.15a	0.02a	0a	C.V. =1.47	C.V.= 1.45	C.V. = 0.00	C.V. 2.32
	(15-20]	7.2	3.42a	0.18a	0.02a	0a				
	(20-25]	7.0	4.03a	0.20a	0.02a	0a				
	(25-30]	7.2	4.64a	0.24a	0.03a	0a				
	(30-35]	7.0	8.10b	0.36a	0.02a	0a				
	(35-40]	6.9	14.23b	0.76a	0.02a	0a				
	(40-45]	7.0	36.00c*	1.80b	0.03a	0.86b				
	(45-50]	7.1	70.00c*	3.47c*	0.03a	1.72b				
$\frac{Q_a}{Q_\pi} = 1.5$ Rel. 1≈0.2-0.6 B^{1}B^2	(0-5]	7.3	1.85a	0.07a	0.01a	0a	m = 3.30	m = 0.14	m = 0.00	m = 0.00
	(5-10]	7.1	2.80a	0.13a	0.01a	0a	σ = 0.69	σ = 0.03	σ =0.005	σ = 0.00
	(10-15]	7.3	3.00a	0.12a	0.01a	0a	C.V. = 0.20	C.V. = 0.21	C.V.= 0.86	C.V. = 0.00
	(15-20]	7.2	3.10a	0.14a	0.01a	0a				
	(20-25]	7.1	3.20a	0.14a	0.01a	0a				
	(25-30]	7.4	3.43a	0.15a	0.01a	0a				
	(30-35]	7.3	3.60a	0.16a	0.02a	0a				
	(35-40]	7.3	3.82a	0.17a	0.01a	0a				
	(40-45]	7.3	3.94a	0.18a	0.02a	0a				
	(45-50]	7.0	4.31b	0.21b	0.01a	0a				
$\frac{Q_a}{Q_\pi} = 3.0$ 1≈0.2-0.6 B^{1}B^2	(0-5]	7.3	2.68a	0.11a	0.01a	0 a	m = 2.96	m = 0.12	m =0.01	m = 0.00
	(5-10]	7.5	2.69a	0.10a	0.01a	0 a	σ = 0.27	σ = 0.01	σ = 0.004	σ =0.00
	(10-15]	7.5	2.70a	0.11a	0.01a	0 a	C. V. = 0.09	C. V. = 0.14	C. V. = 0.4	C.V. = 0.00
	(15-20]	7.5	2.79a	0.12a	0.01a	0 a				
	(20-25]	7.5	2.80a	0.11a	0.01a	0 a				
	(25-30]	7.5	2.98a	0.13a	0.01a	0 a				
	(30-35]	7.5	3.12a	0.13a	0.02a	0 a				
	(35-40]	7.6	3.14a	0.14a	0.01a	0 a				
	(40-45]	7.8	3.35a	0.15a	0.02a	0 a				
	(45-50]	7.6	3.43a	0.15a	0.01a	0 a				
$\frac{Q_a}{Q_\pi} = 0$ 1:5	(0-5]	6.8	1.99a	1.02a	0.15a	0 a	m = 3.60	m = 1.64	m = 0.32	m = 0.00
	(5-10]	6.9	1.95a	0.97a	0.14a	0 a	σ= 2.71	σ = 1.08	σ = 0.35	σ = 0.00
	(10-15]	6.9	2.15a	1.08a	0.13a	0 a	C.V. = 0.75	C.V. = 0.65	C.V. = 1.10	C.V. = 0.00
	(15-20]	7.0	2.12a	1.04a	0.14a	0 a				
	(20-25]	7.0	2.27a	1.12a	0.16a	0a				

Tratamiento	Espesor (cm)	pH	EC (dS m⁻¹)	R_s (g de sales/100 g de suelo)	PS (mmol$_c$ L⁻¹)	ESP	EC	R_s	PS	ESP
B^1B	(25-30]	7.1	2.40a	1.18a	0.18a	0a				
	(30-35]	7.1	2.76a	1.56a	0.16a	0a				
	(35-40]	7.2	3.87a	1.73a	0.31a	0a				
	(40-45]	7.3	6.08b	1.32a	0.63b	0a				
	(45-50]	7.3	10.42c*	4.39b	1.23c	0a				
$\frac{Q_a}{Q_\pi} = 1.5$ 1:5 B^1A^{2*}	(0-5]	6.9	1.99a	0.99a	0.12a	0a	m = 2.11	m = 1.03	m = 0.12	m = 0.00
	(5-10]	7.1	2.03a	1.00a	0.10a	0a	σ = 0.10	σ=0.04	σ =0.02	σ = 0.00
	(10-15]	7.1	2.02a	1.00a	0.11a	0a	C.V. = 0.04	C.V. =0.04	C.V. =0.18	C.V. = 0.00
	(15-20]	7.1	2.05a	0.99a	0.15a	0a				
	(20-25]	7.0	2.06a	1.00a	0.12a	0a				
	(25-30]	7.0	2.12a	1.03a	0.12a	0a				
	(30-35]	7.0	2.14a	1.06a	0.12a	0a				
	(35-40]	7.1	2.20a	1.06a	0.11a	0a				
	(40-45]	7.2	2.27a	1.10b	0.15a	0a				
	(45-50]	7.2	2.27a	1.10b	0.17a	0a				
$\frac{Q_a}{Q_\pi} = 3.0$ 1:5 B^1A^{2*}	(0-5]	7.0	1.93a	0.85a	0.14a	0a	m = 2.00	m = 0.90	m = 0.15	m = 0.00
	(5-10]	7.2	1.95a	0.87a	0.15a	0a	σ = 0.05	σ = 0.02	σ =0.01	σ = 0.00
	(10-15]	7.2	1.94a	0.88a	0.15a	0a	C.V. =0.02	C.V. =0.03	C.V. = 0.06	C.V. = 0.00
	(15-20]	7.2	2.00a	0.90a	0.17a	0a				
	(20-25]	7.3	2.01a	0.91a	0.16a	0a				
	(25-30]	7.3	2.03a	0.92a	0.16a	0a				
	(30-35]	7.3	2.01a	0.90a	0.16a	0a				
	(35-40]	7.4	2.02a	0.91a	0.17a	0a				
	(40-45]	7.3	2.05a	0.93a	0.17a	0a				
	(45-50]	7.3	2.12a	0.94b	0.15a	0a				

Tratamiento	Espesor (cm)	pH	EC (dS m⁻¹)	R_s (g de sales/100 g de suelo)	PS (mmol$_c$ L⁻¹)	ESP	Statisticalparameters			
							EC	R_s	PS	ESP
$\frac{Q_a}{Q_\pi} = 0$. Rel. 1:10 B^1AB^2	(0-5]	7.1	1.98a	1.77a	8.12a	0a	m = 2.91	m = 2.53	m = 14.89	m = 0.21
	(5-10]	6.9	1.88a	1.67a	6.79a	0a	σ=1.76	σ = 1.38	σ= 14.43	σ = 0.67
	(10-15]	6.9	2.01a	1.84a	8.25a	0a	C.V. = 0.60	C.V. = 0.54	C.V. = 0.96	C.V. = 3.22
	(15-20]	6.8	1.97a	1.80a	6.14a	0a				
	(20-25]	6.8	2.11a	1.95a	7.43a	0a				
	(25-30]	6.8	2.12a	1.92a	6.94a	0a				
	(30-35]	6.7	2.34a	2.08a	13.85b	0a				
	(35-40]	6.8	2.93a	2.56a	14.85b	0a				
	(40-45]	6.8	4.36b	3.64b	23.69b	2.14b				
	(45-50]	6.7	7.45b	6.11b	52.93c*	0a				

Treatment	Thickness	pH	EC	Rs	PS					
$\frac{Q_a}{Q_\pi} = 1.5$. Rel. 1:10 B¹A²*	(0-5]	6.7	1.84a	1.74a	6.16a	0a	m = 1.87	m = 1.80	m = 6.69	m = 0
	(5-10]	6.8	1.82a	1.69a	5.98a	0a	σ = 0.05	σ = 0.17	σ = 0.55	σ = 0
	(10-15]	6.8	1.85a	1.72a	6.47a	0a	C.V. = 0.02	C.V. = 0.09	C.V. = 0.08	C.V. = 0
	(15-20]	6.8	1.88a	1.73a	6.86a	0a				
	(20-25]	6.9	1.89a	1.77a	6.59a	0a				
	(25-30]	7.0	1.81a	1.67a	5.97a	0a				
	(30-35]	6.9	1.86a	1.75a	7.31a	0a				
	(35-40]	6.9	1.85a	1.91a	7.06a	0a				
	(40-45]	7.0	1.95a	1.79a	6.95a	0a				
	(45-50]	7.1	1.97a	2.26a	7.59a	0a				
$\frac{Q_a}{Q_\pi} = 3.0$ 1:10 B¹A²*	(0-5]	6.9	1.78a	1.82a	3.66a	0a	m = 1.80	m =1.58	m = 4.59	m = 0
	(5-10]	6.8	1.73a	1.65a	4.39a	0a	σ = 0.04	σ = 0.21	Σ = 0.47	σ = 0
	(10-15]	6.9	1.84a	1.79a	5.19a	0a	C.V.= 0.02	C.V. = 0.13	C.V. = 0.10	C.V. = 0
	(15-20]	6.8	1.79a	1.51a	4.13a	0a				
	(20-25]	6.8	1.80a	1.51a	4.58a	0a				
	(25-30]	6.9	1.78a	1.82a	4.37a	0a				
	(30-35]	6.9	1.77a	1.41a	4.72a	0a				
	(35-40]	6.8	1.85a	1.29a	4.80a	0a				
	(40-45]	6.8	1.79a	1.26a	4.99a	0a				
	(45-50]	6.8	1.88a	1.79a	5.09a	0a				

Where: EC = (Electric conductivity of the soil saturation extract); Rs = Residual salinity; PS = Potential Salinity. $[Cl^- + \frac{1}{2}(SO_4^{-2})]$. A, B = Test of averages between treatments for variables: [1] *`Electric conductivity;* [2] *Residual salinity.a, b, c = Test of averages between thicknesses for variables EC, R$_s$ and PS.*

Note: averages with the same letter are not significantly different. (*) Statistical significance, Duncan α = .05

When comparing the R_s obtained in the ratios 1:5 and 1:10 (extractors of large amounts of soluble salts) and the application of a $\frac{Q_a}{Q_\pi} = 3.0$, with the salt concentration reported by Bernstein [37] as a tolerance threshold of glycophytic plants (2.56 g of salts L^{-1} or CE = 4.0dS m^{-1}), we find that the new salt level of the thickness (0-30 cm] was determined in 0.89 g of salts L^{-1} (EC ≈ 1.97dS m^{-1}) and of 1.68 g of salts L^{-1} (EC ≈ 1.78dS m^{-1}). These concentrations allow the growth and development of crops grown in the region, since the threshold of tolerance to salt stress of maize (*Zea mays L.*), beans (*Phaseolus vulgaris L.*), tomato (*Lycopersicon sculentum L.*) and chili pepper (*Capsicum annum L.*) are greater than this salinity [38]. Results show that the experimental leaching was beneficial, since it temporarily reduced the concentration of salts of the rhizosphere, which is the main goal of the leaching processes in farming soils affected by salts. To prolong the period of salt moderation for as long as possible during crop growth and development, we recommend using layers of over-irrigation, the use of municipal treated wastewater should be a viable option [10]. The leaching process should be accompanied by the application of chemical enhancers to improve the natural soil drainage to evacuate salts, as well as the construction of artificial salt-containment [39].

3. CONCLUSIONS

Leaching with destilled water, applying an active volume of leaching water $\frac{Q_a}{Q_\pi} = 3.0$ equal to 6830.34 m^3 ha^{-1} and its evaluation in a soil-water extraction ratio of 1:10, reduced the excessive salt concentration of the soil thickness (0-30 cm] from 3.09 g of salts100g^{-1}of soil (201.37Mg ha^{-1}) to 1.68g of salts 100 g^{-1}of soil (109.48 Mg ha^{-1}). This indicates a substantial displacement of soluble salts from the higher thicknesses to the lower ones, which are salinized. The new salt pattern of the arable level is in the threshold of tolerance of crops in the region. So it is an active volume and soil-water ratio that evaluated leaching process with more accurately than the 1:5 ratio.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Szabolcs I. Salt affected soils. Boca Ratón FL: CRC Press Inc; 1989.
2. Ruíz CA, Aldaco NR, Montemayor TJ, Fortis HM, Olague RJ, Villagómez GJ. Development and improvement of saline soils by growing forage grasses. Técnica Pecuaria en México. 2007;45:19-24. Spanish.
3. Sánchez BE, Camacho EM, Rodríguez LA, Ortega EM. Characterization of soils affected by salts in irrigation district 110 "Río Verde", Oaxaca, Mexico. Afr. Journal of Agr. Res. 2012(a);7:943-957. DOI.10.5897/AJAR11.1479.
4. Mugdal V, Madaan N, Mugdal A. Biochemical mechanisms of salt tolerance in plants. A. Review. Int. J. Bot. 2010;6:136-143.
Available: http://dx.doi.org/10.3923/ijb.2010.136.143.
5. Strogonov BP. Physiological basis of salt tolerance of plants. (As affected by various types of salinity). Israel Program for Scientific Translations, Jerusalem. Academic of Sciences: USRR; 1964.

6. Sánchez BE, Ortega BV, Domínguez HF, Ortega EM, Can ChA, Sarmiento BD. Soil erosion control using agroforestry terraces in San Pedro Mixtepec, Oaxaca, Mexico. Int. J. of Agri Science. 2013(a);3:423-438.
7. Kovda VA. Arid land irrigation and soil fertility. Problems of salinity, alkalinity and compaction. In: E.B. Wothington, (ed). Arid land irrigation in developing countries: environmental problems and effects. Oxford: Pergamon Press; 1977.
8. Charcas SH, Aguirre RJ, Durán GH. Irrigated soils in region of Rioverde, San Luis Potosí, Mexico. Revista Mexicana de Ciencias Agrícolas. 2012;3:509-523. Spanish.
9. González R del C, Ortega M, Ramírez C, Rone JL. Establecimiento de la relación funcional entre láminas de lavado, sales desplazadas y salinidad residual en suelos salinos. Agrociencia. 1985;59:131-147. Spanish.
10. Sánchez BE, Ortega EM, Sandoval OG, Hernández VR, Estrada VC. Lavado de sales en suelos aluviales costeros de Oaxaca, México, con aguas residuales municipales tratadas. Rev. Int. Contam. Ambie. 2012(b);28:343-360.Spanish.
11. Panin PS. The lixiviation of salts in soils subject to leaching. Novosbirsk. Nauka; 1968.
12. Litovchenko AA. Leaching of saline soils in the Omsk Oblast by depp furrow irrigation. Sov. Soil Sci. 1989;21:59-66.
13. López RE. Geology general and Mexico. Mexico: Trillas; 1993. Spanish.
14. Food and Agriculture Organization of the United Nations: World reference base for soil resources. Report 84, Rome; 1998.
15. Instituto Nacional de Estadística, Geografía e Informática. Geographical synthesis of San Luis Potosí. México: INEGI; 2008.
16. Secretaría del Medio Ambiente y Recursos Naturales. Mexican Official Standard NOM-021-RECNAT-2000. Specifications of fertility, salinity and soil classification. Studies, sampling and analysis. Mexico: Official Journal of the Federation; 2002.
17. Richards LA (ed). Diagnosis and rehabilitation of saline soils and sodics. Salinity Laboratory. USDA, Manual 60. México: LIMUSA; 1985. Spanish.
18. Palmer GR, Troeh RF. Introduction to soil science. Manual of Laboratory. Mexico: Editor SA; 1979.
19. Munsell Color. Munsell soil color charts. New York: Gretag Mcbeth; 2000.
20. Safanov GA, Galinski SD, Mitronkyn YE. Stochastic model of leaching saline sulphatic soils. In: Academy of Sciences of the USSR (ed). Mathematical Methods in Biology and Soil Science. Moscow: Nauka; 1976.
21. SAS Institute Inc. SAS/STATE® Release 0.13, User´s guide. Cary NC: SAS Institute Inc; 2006.
22. Teterin UP. Determination of total soil and natural water salinity by the electric conductivity method. Sov. Soil Sci. 1968;10:1455-1460.
23. Sarabia M F, Cisneros AR, Aceves de Alba J, Durán G M, Castro LJ. Calidad del agua de riego en suelos agrícolas y cultivos del valle de San Luis Potosí. Rev. Int. Contam. Ambie. 2011;27:103-113.
24. Maas EV. Salt tolerance of plants. Appl. Agr. Res. 1986;1:12-26.
25. Ayers RS, Westcot DL. Water quality in agriculture. FAO: Irrigation and drainage. 1987;29:1-87.
26. Can ChA, Ramírez C, Ortega M, Trejo C, Cruz JD. Evaluation of the sodium adsorption ratio in waters of the Tulancingo River, State of Hidalgo, Mexico. Terra Latinoam. 2008;26:243-252. Spanish.
27. Keenan W, Kleinfelter ChD, Wood HJ. Química General Universitaria. Trad. A. Eroles Gómez. México: CECSA; 1990.
28. Volobuyev VR. General features of changes in salt amounts in the soils of irrigated and reclaimed land. Sov. Soil Sci. 1964;5:47-56.
29. Hopkins GW. Introduction to plant physiology. New York. Jhon Wiley & Sons; 1995.

30. Szabolcs I 1994. Soil and water salinization and desertification. In: Anaya M, Pascual M, and Zárate R, editors. Proceedings of the IV International conference on desert development. México. Colegio de Postgraduados; 1993.

31. Can ChA, Ramírez C, Ortega M, Trejo C, Cruz JD. Evaluation of the sodium adsorption ratio in waters of the Tulancingo River, State of Hidalgo, Mexico. Terra Latinoam. 2008;26:243-252. Spanish.

32. Sharma RC, Mandal AK, Singh R. Delineation and Characterization of Waterlogged and Salt-affected Soils in Gandak Command Area of Bihar for Reclamation and Management. J. of the Indian Soc. of Soil Sci. 2011;59:315-320.

33. FitzPatrick E. Soils: Their formation, classification and distribution. USA: Longman; 1984.

34. Coras PM. Calidad del agua de riego. Departamento de Fisiología Vegetal. 1ª. ed. México: Universidad Autónoma Chapingo; 2000. Spanish.

35. Gili SP, Marando IG, Irisarri EJ, Sagardoy RM. Effect of soil leaching techniques and fertilization on the salinity of soils of the upper Río Negro Valley and Neuquén, Argentine. Agricultura técnica. 2004;64:295-304. Spanish.

36. Pizarro F. Drainage and reclamation of saline soils. Madrid: Agrícola Española; 1985.

37. Bernstein L. Salt tolerance of plants. Agric. Inf. Bull. No. 283. USDA, Washington, D.C. 1964;23.

38. Maas EV, Hoffman GJ. Crop salt tolerance current assessment. J. Irrig. Drain. Div. 1977;103:115-154.

39. Manjunatha MV, Oosterbaan RJ, Boonstra J, Hebbara M. Salt and water balance studies using SALTMOD for Tungabhadra command, Peninsular India. J. of the Indian Soc. of Soil Sci. 2011;59:321-328.

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