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Column leaching experiments on saline soils of different textures in Sistan plain

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Abstract

Salinization is the main characteristic of soils in arid and semi-arid regions which reduce the agricultural potential of irrigated lands. Therefore, soil reclamation as well as determination of the leaching requirement for salt control is very important for better plant growth. In this study, the effects of leaching on saline soils of Sistan region, southeast of Iran were examined using unsaturated disturbed soil columns. The experiment was conducted on four texture types (loam, sandy clay loam, sandy loam and clay loam) and three replications. Soil samples were purred in polyvinyl chloride (PVC) cylinders and leaching procedures were conducted in 10 stages with up to 5 pore volumes. Effluent from each column was collected and evaluated in terms of Na^+, K^+, Ca^{2+}, Mg^{2+} and EC. At the end of the study, soil columns were cut and their corresponding samples were analyzed for Na^+, K^+, Ca^{2+}, Mg^{2+} and EC. The results of leaching experiments showed that the water used in this study could reduce solute concentration and thus, this soil does not need any amendment. For most soil textures, it was also observed that almost 85% of the salts were leached after the fifth stage of the leaching process. According to the results, ions entry into the effluent solution is fast in the coarse textured soils. So, the difference between the amounts of irrigation water needed to transport the salts and leach the saline soils can be attributed to the soil texture. It seems that the main reason for these reactions is the cation exchange.

Keywords: Cation exchange; Leaching process; Sistan, Soil columns; Soil texture; Solute concentration

1. Introduction

Soil salinity is one of the most important degradation processes that reduce the agricultural potential of arid and semi-arid irrigated lands and so affects crop productivity and sustainability of irrigated agriculture worldwide (Corwin *et al*., 2007; Kahlon *et al*., 2013). In Iran, almost half of the irrigated lands have changed to different types of saline soils which resulted in average yield losses of up to 50%. The main reasons for the salinization here are the low rainfall and high evaporation amounts as well as low quality of irrigation water. This situation causes not only agricultural problems but also it has negative social and economic effects on Iranian communities (Qureshi *et al*., 2007). Therefore, the desalinization of soils is necessary to provide a sustainable irrigated agriculture (Kalhon, 2013).

To control salinity in the root zone for better plant growth, more water than required to meet crop evapotranspiration demands, must be passed through the root zone to leach excessive soluble salts (Corwin *et al*., 2007). However, to reclaim a saline-sodic soil, it is necessary to remove Na^+ from the soil cation exchange complex by adding Ca^{2+} through the application of some chemical amendments, e.g. gypsum or calcium chloride.

Soil salt leaching experiment is one of the efficient methods for determining the amount of

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water and chemical amendments required to remove excess salts from the root zone and hence, enhance the productivity of salt-affected soils (Mostafazade-Fard *et al*., 2008). For instance, Maszkowska *et al*. (2013) showed that the release potential of salts from soil can be determined through laboratory batch and column leaching tests. Soil column studies are also used to investigate the effect of wastewater and treated water on soil and water quality (Jalali *et al*., 2008). A study was conducted by Chen et al. (2003) on the leaching of phosphorus and copper in dredging sediments of sandy soil cylinders. The results showed that leaching of dredging sediments which are rich in phosphorous and copper may cause a significant movement of these elements to the bottom of cylinders when their concentrations in 15 cm depth were more than that in the 5 cm depth. López-Aguirre et al. (2007) investigated salt leaching process in alkaline soils by application of sulphur. The results showed that after applying 1.3 pore volumes (pv) of water, cations such as potassium and sodium were strongly leached; however, by applying 0.25 pv, a large amount of calcium and manganese ions were leached. In addition, the variation of ions was meaningful during the leaching process. Soil column studies were conducted to examine the adsorption and movement of applied potassium in a sandy soil (Kolahchi and Jalali, 2007) and to investigate interactions between exogenous rare earth elements and phosphorus leaching (Liang *et al*., 2010). Soil column experiments were also applied to assess the effects of irrigation with wastewater on the quality of soil and groundwater (Jalali *et al*., 2008), to investigate the effect of saline-sodic irrigation water on the leaching of potassium (Jalali, 2011), to study the vertical transport of phosphorous received from seven different sources of potassium fertilizer in a sandy soil (Kang *et al*., 2011) and to investigate leaching of a soil contaminated by chromium and nickel (Jean-Soro *et al*., 2012). Zarabi and Jalali (2012) and Sharma and Sharma (2013) also used a leaching column to investigate the leaching of nitrate and ammonium from calcareous soil amended with organic residues and to study the influence of accompanying anions on potassium leaching at a potato field by considering different soil texture types, respectively.

The leaching requirement of a soil depends on various factors such as texture, infiltration, depth of soil, initial salinity and type of existent salts (Kahlon *et al*., 2013). The effect of soil texture on leaching requirement of a saline-sodic soil receiving various amounts of irrigation water was investigated by Kahlon *et al*. (2013). They concluded that leaching had a positive effect on the amount of salts leached. Moreover, the highest amount of salts was removed from sandy clay loam in comparison with loamy sand and silty clay loam soil.

The serious problem of salinization in Sistan plain needs to be studied by exploring the feasible and cost effective land reclamation methods. However, there are limited studies performed on desalinization in this region. The aim of this study was to use soil column experiments to study the effect of different irrigation amounts on salt leaching in soils of different texture types from Sistan plain. The study was partly performed to explore the ability of available irrigation water to leach the salts down through the soil profile and prevent accumulation. The results of this study could be used as guide in future soil reclamation projects, to properly determine leaching requirements for salinity control.

2. Materials and Methods

In this study, the effects of leaching on saline soils were examined by unsaturated disturbed soil columns in the laboratory. Leaching experiments were carried out on four soil types with three replications. The soil types included four types of soil texture which are more dominant in Sistan plain, southeast of Iran. Sistan plain used to have very fertile soils and diverse agricultural productions. However, since the mid-1990s, it has been confronted with severe salinization and soil degradation due to the occurrence of frequent droughts, more recently, from 1999-2005. Soil samples were collected from 0-30 cm depth. The soil samples were air dried, gently ground and passed through a 2-mm sieve. The soil saturated paste extract was used for measuring soluble ion concentrations. Soil texture, bulk density (BD) and particle density were measured using standard methods (Klute, 1986). EC and pH were determined by an EC-meter and a pH-meter, respectively, Na^+ and K^+ were measured by a flame photometer, Ca^{2+} and Mg^{2+} were determined by titration and the organic carbon (OC) content was obtained by the modified Walkley Black method (Nelson and Sommers, 1996).

For the leaching experiments, 12 polyvinyl chloride (PVC)-cylinders with a diameter of 10 cm and height of 50 cm were prepared. A sandy filter was improvised at the bottom of cylinders to prevent the blockage of the outlet by small soil ingredients. Cylinders were full with soils by uniform taping to provide the original bulk densities of undisturbed soils. A filter paper was placed on the soil surface to prevent soil disturbance when the leaching water was added. Moreover, a suitable surface cover was prepared to prevent evaporation from the soil surface during the experiments. After preparing the cylinders, leaching experiments were conducted for two months. Leaching was performed in 10 steps with irrigation water amounts of 0.25 to 5 pore volumes (pv). One pore volume is the volume of water that a saturated soil holds in its pores. The leaching experiment was conducted in three replicates for each soil type.

Effluents from cylinders were collected using some suitable cans and analyzed for potassium, sodium, calcium, magnesium and EC. Leaching results were explained by the breakthrough curves (BTCs). Breakthrough curves indicate the relation between cations and/or anions and effluents collected from the cylinders (Kolahchi and Jalali, 2007). After leaching, soil columns were split open and cut into 3 sections, 10 cm each. Soil samples taken from different column depths were analyzed for potassium, sodium, calcium, magnesium and EC.

The comparison of means using Duncan' test was performed with SPSS v. 13 at a significance level of 5%. The BTC for each element was drawn within the Excel 2010 environment.

3. Results and Discussion

The basic physical and chemical properties of soils used in this study are shown in Tables 1 and 2, respectively. As seen in Table 1, the bulk density for different types of soil texture ranges from 1.42 to 1.58 g/cm^3. The values of soil intake rate are 0.75, 1.54, 1.75 and 1.32 cm/h for clay loam, sandy clay loam, sandy loam and loam, respectively. According to the soil chemical analysis (Table 2), the EC_e values of soil types range between 8.7 and 73 dS/m and pH is about 6.4- 8. Sandy loam has the highest amount of Na^+, K^+ and Mg^{2+}, while loam has the highest amount of Ca^{2+}. The results of chemical analysis of the water used in the leaching process (Table 3) indicate that the water has a low amount of EC_e (0.53 dS/m) and SAR (4.11).

Table 1. Relevant soil physical properties in a depth of 0-30 cm

Soil texture	Bulk density	Particle density	Intake rate
	(gr/cm^3)		(cm/hr)
Loam	1.5	2.57	1.32
Sandy loam	1.58	2.51	1.75
Sandy clay loam	1.55	2.71	1.54
Clay loam	1.42	2.68	0.75

Table 2. Relevant soil chemical properties in a depth of 0-30 cm

Soil texture	pH	SAR	EC_e	Na^+	K^+	Mg^{2+}	Ca^{2+}
	-	-	(dSm^{-1})		(meq/l)		
Loam	7.93	4.2	8.7	42	26	131	77
Sandy loam	6.38	9.8	29.5	93	44	136.2	45
Sandy clay loam	7.5	8.8	73	66.5	27	83	31
Clay loam	6.4	5.9	45	52	36	88	70

Table 3. Relevant chemical properties of water used in the leaching experiments

pH	EC	SAR	K^+	$Ca^{2+}+Mg^{2+}$	Na^+
-	(dSm^{-1})	-		(meq/l)	
8.5	0.53	4.11	0.7	3.53	5.46

Sodium leaching

The breakthrough curves of sodium for the four types of soil texture are shown in Figure 1. This figure shows sodium concentration in the leachate solution versus the cumulative amount of leaching solution passed through the soil column. Sodium concentration is in its highest amount initially, and reduced to the minimum amount (5 to 8 meq/l) of about 5 pv for all soil textures except the sandy clay loam, for which the minimum amount (13.7 meq/l) was observed at 3 pv. It seems that the presence of calcium as a competing ion in the leaching water may repel sodium in soil exchange complex, resulting to the highest initial concentration of sodium in the leachate solution. After a sharp decrease at the first stage of the leaching experiment, sodium concentration gradually decreased for all the soil textures. The initial high amount of sodium concentration in the leachate solution was also observed in a study by Jalali et al. (2008). The sodium concentration in the leaching solution was higher in sandy clay loam and sandy loam than in the other two types. This could be mainly due to the lower cation exchange capacity of light-textured soils compared to heavy-textured soils (Lael *et al*., 2009; Kahlon *et al*., 2013). However, higher macrospores of coarse textured soils than fine textured soils may also result in a relatively higher amount of leachate and thus salt removal (Mostafazadeh-Fard *et al*., 2008; Kahlon, *et al*., 2013).

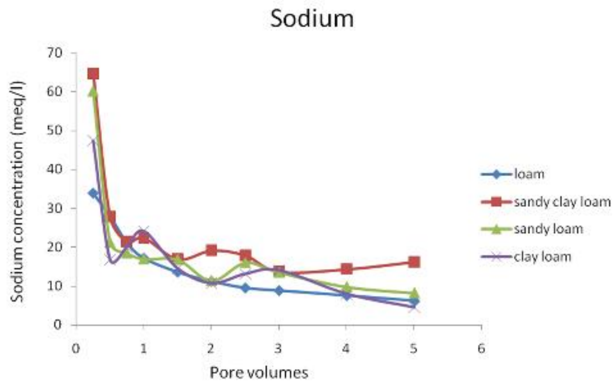

Fig. 1. Breakthrough curves of sodium for the four texture types

Potassium leaching

Figure 2 shows changes in the potassium concentration of the outlet drainage water from the soil columns, when leached with cumulative amounts of irrigation water. As seen, for different soil textures, the maximum potassium concentration was observed at the beginning of the leaching process, and then its amount decreased in a similar trend. Potassium leaching in loam and clay loam soils is lower than in sandy loam and sandy clay loam soils because heavy-textured soils have higher cation exchange capacity (CEC) compared to light-textured soils (Fageria, 2008). This is due to the larger surface of clay particles in comparison with sand minerals, which increases the ability of clay particles to hold and retain potassium. Sharma and Sharma (2013) also found a smaller maximum amount of leached K in a clay loam than in a sandy loam after four times of leaching. Also, the CEC of a soil varies according to the amount of organic matter and clay type, e.g. kaolinite has a smaller CEC than illite and smectite (Moore, 1998). The soils of Sistan plain are poor in organic matter and the type of clay is often kaolinite and illite. Leached potassium at the early leaching stage for loam, sandy clay loam, sandy loam and clay loam were about 42, 37, 32 and 28%, respectively. Kolahchi and Jalali (2007) concluded that the presence of Ca^{2+} in irrigation water and mineral elements in soil may result in a high potassium leaching rate.

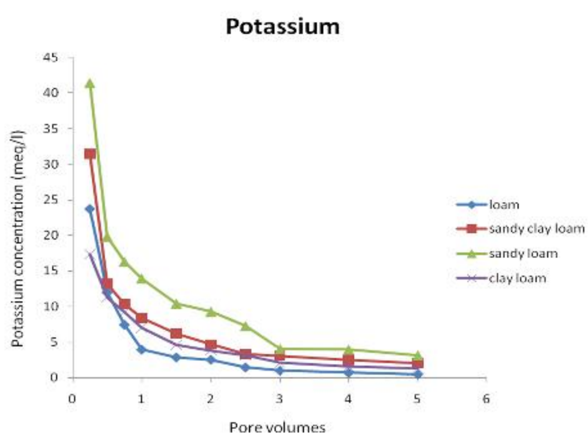

Fig. 2. Breakthrough curves of potassium for the four texture types

Calcium leaching

Figure 3 shows the breakthrough curve of calcium for soils with different texture types. Similar to potassium concentration, the maximum calcium leaching rate was observed at the beginning of the leaching process for all texture types. Unlike sodium and potassium, a higher concentration of calcium was seen for heavy-textured soils than light-textured soils. Leached calcium rates at the first stage of leaching (i.e. after 0.25 pv) were approximately 35, 44, 33 and 42%, respectively, in loam, sandy clay loam, sandy loam and clay loam. In loam, sandy loam and clay loam, more than 80% and in sandy clay loam, more than 90% of calcium were leached after 2 pv.

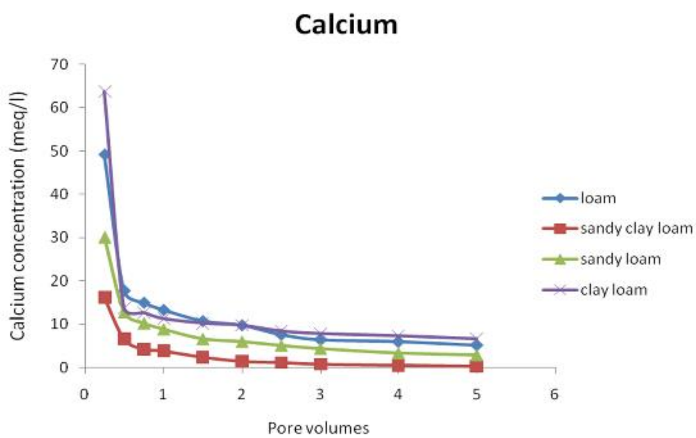

Fig. 3. Breakthrough curves of calcium for the four texture types

Magnesium leaching

Figure 4 shows the concentrations of magnesium leached out, corresponding to different pore volumes in different soils. Again, the maximum magnesium leaching rate was observed at the first pore volume. The leached magnesium rate at the beginning of the process in loam, sandy loam, sandy clay loam and clay loam were 37, 30, 34 and 43%, respectively. Jalali and Ranjbar (2009) found that due to the increase of calcium concentration in leaching solution and higher ability of calcium in competition of calcium and magnesium for absorption in the exchangeable phase, magnesium rate in the leached water increased as compared to calcium.

Some soil types had different behaviors at different leaching stages. While the magnesium concentration in the effluent of loam and clay loam textured-soils decreased continuously up to the last leaching stage. In the other two types, alternately increasing and decreasing trends were observed up to the 8th stage of leaching, after which almost a constant trend was observed for all soil types.

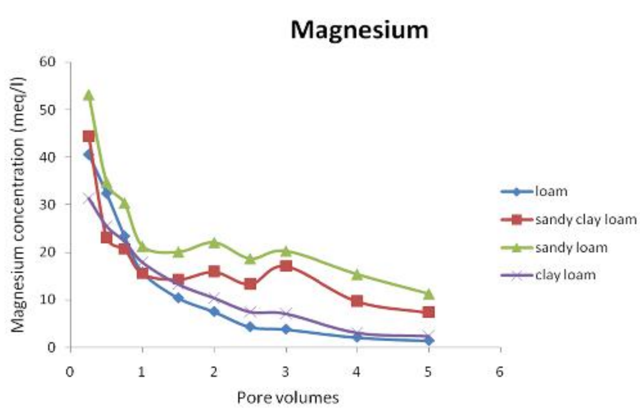

Fig. 4. Breakthrough curves of magnesium for the four texture types

Electrical conductivity (EC)

Figure 5 indicates changes in the total concentration of soluble salts in effluents during ten stages of leaching. As seen, the maximum EC in effluent was observed for the first stage (0.25 pv) and after that, there was a sharp decrease in EC values of leached water for all soil types. It could be concluded that the water used for leaching experiment, has a high removal efficiency of minerals from the soil profile. Also, it was found that different texture types behave differently in the process of removing soluble salts from the soil. Sandy clay loam had the highest amount of EC (110 dS/m) when washed with 0.25 pv of water, while the lowest EC (15.47 dS/m) was observed in loam. Kahlon *et al*. (2013) also reported similar results regarding the effect of soil texture and different pore volumes of water on salt removal from a saline-sodic soil. As seen in Figure 5, almost all soluble salts were leached out from loam soil at 1 pv and from sandy clay loam, sandy loam and clay loam at 3 pv. Comparing the EC breakthrough curve with other cation breakthrough curves revealed that the trend in EC values variation corresponding to each texture type is very similar to the trend of sodium variation (Figure 1). Considering that the dominant ion in drainage water from soil columns is sodium, it is natural that the EC breakthrough curve is most similar to the Na^+ breakthrough curve. In fact, the lower Na affinity to the CEC in comparison with other exchangeable cations (Ca^{2+}, Mg^{2+} and K^+) resulted in higher Na concentrations in soil solution and consequently to higher Na movement through the soil profile (Lael *et al*., 2009). The increase of sodium rate in the solution phase enhances EC rate in the effluent, especially at the first stage of the leaching process.

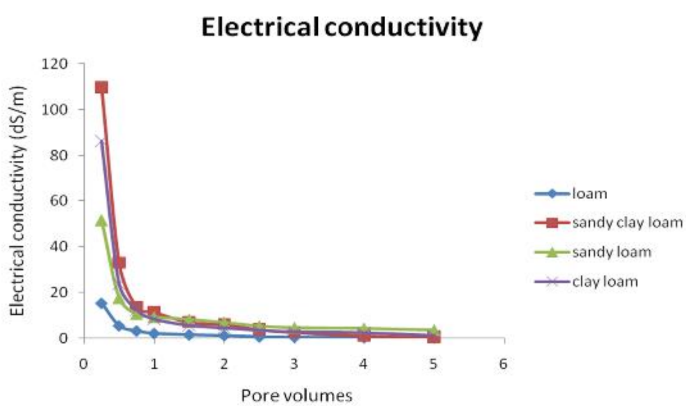

Fig. 5. Changes in electrical conductivity of effluents in soils with different textures

Soil samples

At the end of the leaching experiment, the soil columns were sliced into 10 cm thickness pieces and for each, EC values and the concentrations of sodium, potassium, calcium and magnesium were measured. For each soil texture type, the average measured values of soil minerals and EC in the three replications was obtained (Figure 6). As seen, sodium concentration increased with increasing soil depth in all the texture types. In other words, sodium was leached from the upper depths and deposited in the lower depths. The lowest Na^+ (25.77 meq/l) was observed in sandy loam followed by sandy clay loam (26.59 meq/l), clay loam (29.71 meq/l) and loam (34.85 meq/l) in the upper layer. Statistical analysis showed that at depths of 0-10 and 10-20 cm, there was no significant difference ($p<0.05$) between sandy loam and sandy clay loam in terms of mean sodium concentration, while their difference with other types was significant. The difference between sandy clay loam and other types was not statistically significant ($p<0.05$) in a depth of 20-30 cm.

According to Figure 6, except for sandy loam, potassium concentration increased with depth; the lowest potassium amount was observed in the upper layer. Sandy loam has a different behavior from the other types in potassium removal which could be due to its relatively coarse texture (Donahue *et al*., 1977). According to Figure 2, much higher potassium was removed from sandy loam compared to other soil types after 3 pv of irrigation water. It could then be concluded that in soils poor in clay, potassium may be leached considerably through the soil profile. Statistical analysis showed that there was no significant difference between loam, sandy loam and clay loam textures in leaching potassium from the upper (0-10 cm) soil depth. However, their difference with sandy clay loam was significant. At a depth of 20-30 cm, loam, sandy clay loam and clay loam were not statistically ($P<0.5$) different in washing potassium, while they had a significant difference with sandy loam.

In terms of calcium concentration in soil slices, Figure 6 shows that calcium was more leached from the soil surface in light-textured soils than heavy-textured soils. Calcium concentration in loam and clay loam were similar but they differ from the two other types; this is due to their similarity in texture type. At a depth of 0-10 cm, there was no significant difference between calcium mean concentration in sandy loam and clay loam, but it was significantly different from the other types. No significant difference was observed between loam and sandy loam, while these two were significantly different from other texture types at the 10-20 cm soil depth. The difference between texture types in leaching calcium was not significant at the depth of 20-30 cm.

As shown in Figure 6, in both clay loam and sandy clay loam, the maximum magnesium concentration was observed in upper depths. Statistical analysis showed that in depth of 20-30 cm, there was no significant difference ($p<0.05$) between loam, sandy clay loam and clay loam in leaching magnesium, while they were significantly different from sandy loam. There was no difference between all texture types in 10-20 cm depth. Also, except loam, the other texture types were not significantly different in transporting magnesium at the 0-10 cm depth.

Also, as shown in Figure 6, the variation of EC values of samples taken from three soil depth intervals correspond to each texture type. As seen, EC values in different depths changed differently in sandy loam and sandy clay loam compared to loam and clay loam. While EC values increased through the soil profile in coarse-textured soils it had inverse trend in fine-textured soils. According to the statistical analysis, at a depth of 0-10 cm, both sandy loam and sandy clay loam were not significantly different in salt transport, while they were significantly different from loam and clay loam. The latter two had the highest amount of EC values (5.33 and 6.79 dS/m for clay loam and loam, respectively). In the depth of 10-20 cm, the highest mean EC values (5.39 dS/m) was recorded in loam. This type was statistically ($p<0.05$) different from the other types. For the deepest layer (20-30 cm), there was no significant difference between the four texture types in leaching salts from soil.

4. Conclusion

In this study, leaching experiments were performed on saline soils of Sistan plain through unsaturated disturbed soil columns. The results showed that the current irrigation water could efficiently reduce soil salinity and salts concentration. In almost all the textures, 85% of salts were leached after the fifth leaching stage. So, these soils do not need any amendments for soil reclamation. According to the results, the effect of coarse-textured soil on the ion transport is more than that of fine-textured soil as the entry of most solute into the effluent was fast in coarse-textured soil. Therefore, it could be concluded that although coarse-textured soils have relatively low total porosity, they are mostly macro pores which results in a relatively high volume of leachate and salt removal. Moreover, clay played an important role in maintaining and transporting soil ions. Light-textured soils with low clay content and small buffer capacity had higher K^+ concentration in the soil solution than heavy-textured soils. Therefore, the difference between irrigation water amounts required for transporting and removing salts from the soil profile is attributed to the soil texture. It seems that the main reason for these reactions is cation exchange. In general, the results of this study could be helpful in better management of saline soils and the optimization of large investments in land reclamation programs in Sistan plain, southeast of Iran.

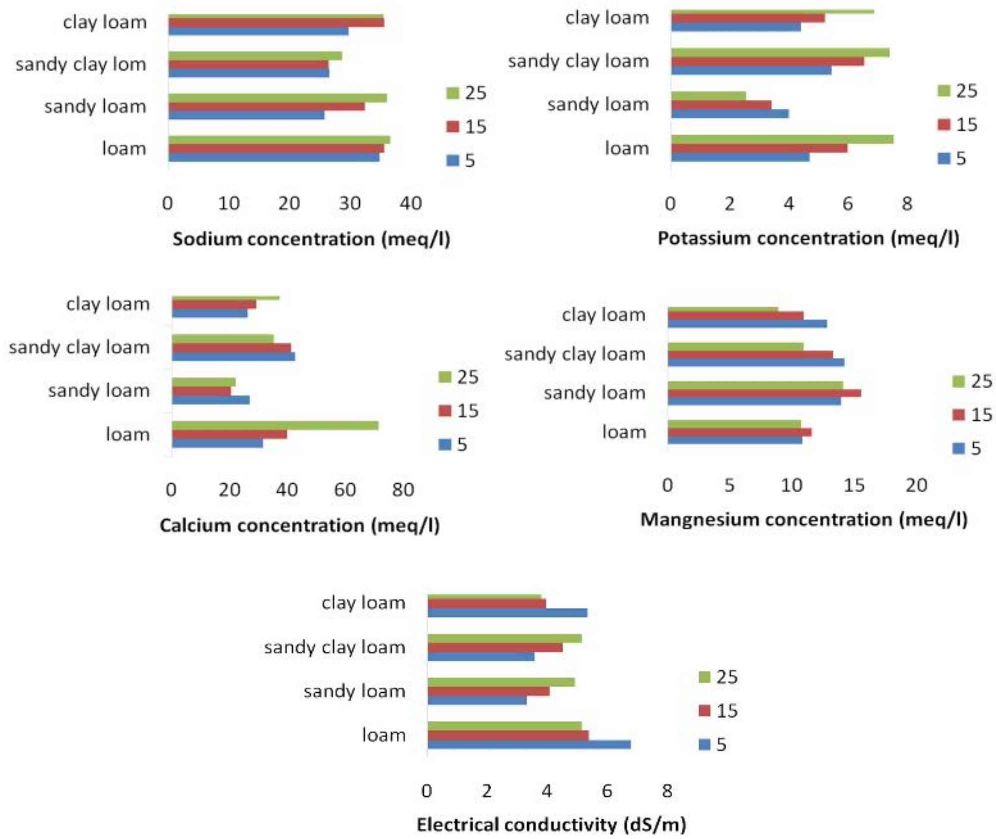

Fig. 6. Measured concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+} and EC of the soil slices obtained after leaching. Here, 5, 15 and 25 means 0-10, 10-20 and 20-30 cm soil depth intervals, respectively

References

Chen, X.Y., G.W. Zhu, G.M. Tian, H. Chen, 2003. Phosphorus and copper leaching from dredged sediment applied on a sandy loam soil column study. Chemosphere, 53; 1179-1187.

Corwin, D.L., J.D. Rhoades, J. Simunek, 2007. Leaching requirement for soil salinity control: Steady-state versus transient models. Agricultural Water Management, 90 (3); 165-180.

Donahue, R.L., R.W. Miller, J.C. Shickluna, 1977. Soils: An Introduction to Soils and Plant Growth. Prentice-Hall.

Fageria, N.K., 2008. The Use of Nutrients in Crop Plants. CRC Press, 448 pages.

Jalali, M., 2011. Effect of saline-sodic solutions on column leaching of potassium from sandy soil. Archives of Agronomy and Soil Science, 57 (4); 377-390.

Jalali, M., F. Ranjbar, 2009. Effects of sodic water on soil sodicity and nutrient leaching in poultry and sheep manure amended soils. Geoderma, 153; 194-204.

Jalali, M., H. Merikhpour, M.J. Kaledhonkar, S.E.A.T.M. Van Der Zee. 2008. Effects of wastewater irrigation on soil sodicity and nutrient leaching in calcareous soils. Journal of Agricultural Water Management, 95 (2); 143-153.

Jean-Soro, L., F. Bordas, J.C. Bollinger, 2012. Column leaching of choromium and nickel from a contaminated soil using EDTA and citric acid. Environmental Pollution, 164; 175-181.

Kang, J., A. Amoozegar, D. Hesterberg, D.L. Osmond, 2011. Phosphorus leaching in a sandy soil as affected by organic and inorganic fertilizer sources. Geoderma, 161; 194-201.

Kahlon, U.Z., G. Murtaza, B. Murtaza, A. Hussain, 2013. Different response of soil texture for leaching of salts receiving different pore volumes of water in saline-sodic soil column. Pakistan Journal of Agricultural Sciences, 50 (2); 191-198.

Klute, A., 1986. Methods of soil analysis. Part 1–Physical and Mineralogical Methods. 2nd. ed Agronomy Monograph No 9: American Society of Agronomy/Soil Science Society of America (Ed. A Klute), Madison, Wisconsin.

Kolahchi, Z., M. Jalali, 2007. Effect of water quality on the leaching of potassium from sandy soil. Journal of Arid Environments, 68(4); 624-639.

Liang, T., W.C. Song, L.Q. Wang, P.J.A. Kleinman, H.Y. Cao, 2010. Interactions between exogenous rare earth elements and phosphorus leaching in packed soil columns. Pedosphere, 20(5); 616-622.

López-Aguirre, J.G., J. Farias-Larios, J. Molina-Ochoa, S. Aguilar-Espinosa, M. del R. Flores-Bello, M. González-Ramírez, 2007. Salt leaching process in an alkaline soil treated with elemental sulphur under dry tropic conditions. World Journal of Agricultural Sciences, 3(3); 356-362.

Maszkowska, J., M. Kołodziejska, A. Białk-Bielińska, W. Mrozik, J. Kumirska, P. Stepnowski, 2013. Column and batch tests of sulfonamide leaching from different types of soil. Journal of Hazardous Materials, 260; 468-474.

Moore, G., P. Dolling, B. Porter, L. Leonard, 1998. Soil Acidity. In: Soil Guide: A Handbook for Understanding and Managing Agricultural Soils. (Ed. G. Moore) Agriculture Western Australia Bulletin No. 4343.

Mostafazadeh-Fard, B., M. Heidarpour, A. Aghakhani, M. Feizi, 2008. Effects of leaching on soil desalinization for wheat crop in an arid region. Plant Soil Environ, 54 (1); 20–29.

Nelson, D.W, L.E. Sommers, 1996. Methods of Soil Analysis. Part 3. Chemical Methods. Soil Science Society of America Book Series no.5, pp. 961-1010.

Pereira Leal, R.M., U. Herpin, A.F. da Fonseca, L.P. Firme, C.R. Montes, A.J., Melfi, 2009. Sodicity and salinity in a Brazilian oxisol cultivated with sugarcane irrigated with wastewater. Agricultural Water Management, 96; 307-316.

Qureshi, A.S., M. Qadir, N. Heydari, H. Turral, A. Javadi, 2007. A review of management strategies for salt-prone land and water resources in Iran. Colombo, Sri Lanka: International Water Management Institute. 30p. (IWMI Working Paper 125).

Sharma, V., K.N. Sharma, 2013. Influence of accompanying anions on potassium retention and leaching in potato growing alluvial soils. Pedosphere, 23(4); 464-471.

Zarabi, M., M. Jalali, 2012. Leaching of nitrogen and base cations from calcareous soil amended with organic residues. Environmental Technology, 33 (13-15); 1577-1588.