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Desalinization of Aggregated Saline Soil: Experiments on Columns of Spherical Aggregates

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Abstract: Salt affected soils may be reclaimed by leaching, but continuously pending the soil surface and allowing infiltration requires large quantities of water. During such leaching bypass flow occurs, consequently solute within the aggregates is transported much slower decreasing the overall leaching efficiency. The alternate is intermittent leaching which provides time for diffusion of solute from aggregates. Flux density and aggregate size have great effect on the leaching efficiency. Thus leaching of columns of spherical aggregates of three different sizes was carried out in the laboratory with continuous and intermittent leaching to explore the effect of aggregate size and the water flux density on the leaching efficiency. In continuous leaching the inflow of fresh water into column was set equal to outflow of leachate so that the aggregates were bathing in fresh water all the time. In case of intermittent leaching the inflow and out flow of water were regularly interrupted after certain times so as to provide time for salts in aggregates to diffuse out in the macro pores around the aggregates. Experimental results showed that leaching efficiency with intermittent leaching increased with increasing water flux density and aggregate diameter. Depending on the size of aggregate and water flux density water savings up to 65% were obtained under laboratory conditions by using intermittent leaching compared to that of continuous leaching.

Key words: Leaching, Intermittent, Diffusion, Salts, Macro pores, Microforms, Soil

Introduction

The world population is increasing day by day at an alarming rate especially in under-developed countries. It is expected that the population of the world will grow from six billion today to at least eight billion by the year 2025, with 90% of the increase being added to the developing world, that will ultimately result in increased demand for food and fibre. The existing cultivated lands are unable to meet the increasing food and fibre requirements of the world. In the past, much of the demand for growth in food and fibre production has been met by increasing the land under irrigated agriculture. Today the availability of new land is limited, while on the other hand, due to over irrigation, high water tables and poor water management practices, fertile and productive soils are turning into non-productive saline/sodic and waterlogged soils, which result in less crop production and eventually abandonment of the land. According to estimates by FAO and UNESCO nearly 50% of the irrigated land in the arid and semi-arid regions of the world have some degree of soil sanitization problems. It is estimated that the world as a whole is looking at least 3 hectares of fertile land every minute due to sanitization /codification (Abrol *et al.*, 1988). Thus, reclamation of existing saline soils is of primary importance. The developing countries of the world are now paying more attention to the reclamation of these salt affected soils to meet their food and fibre requirements.

Aggregate soil is a complex porous material with two distinct pore regions i.e. microforms within aggregates and macro pores around the aggregates. Macro pores provide passage for the mixing and flow of the solute while the microforms act as sink or source of the solute (Youngs and Leeds-Harrison, 1990). The solute transfer from micro to macro pores is only by diffusion (Youngs and Leeds-Harrison, 1990, Rose, 1970 and Biggar and Nielsen, 1967) which is a slow process. Thus during reclamation of saline soils by continuous leaching large quantities of water are wasted due to madrepore flow which are often minimized by using intermittent leaching because intermittent leaching provides time for the salt diffusion during *rest* periods. With intermittent leaching water savings up to 25% are observed under laboratory conditions (Al-Sibai *et al.*, 1997). The water savings can further be obtained only by minimizing madrepore flow during *on* periods of leaching. This paper describes laboratory experiments of leaching of columns of aggregates under initial conditions similar to those, which are usually observed in the field (empty macro pores) for investigating the effect of aggregate size and the flux density on the rate of leaching.

Materials and methods

Leaching experiments were carried out in columns of baked clay spherical aggregates (Cheraghi, 1998) of three different sizes i.e. 8 mm, 16 mm and 31 mm. Aggregates were saturated overnight by partially submerging them in 0.1N KCl solution having an Electrical Conductivity (EC) of 14 dS/m in a shallow tray in order to avoid any air trapped in the aggregates. The aggregates were left for overnight in the solution for saturation. After 24 hours a thin film of solute was observed on the aggregates indicating saturation of aggregates. The saturated aggregates were then poured carefully into a glass cylinder and the cylinder was vibrated for 5 minutes to get a maximum density of packing. The diameter of the column was 94 mm and the length of the aggregates filling the column was 170 mm for all three sizes of aggregates. Before leaching column macro pores were filled with de-ionised water supplied from the bottom of the column in order to avoid air entrapment. Within a minute when all the aggregates were submerged in the de-ionised water, the supply was immediately disconnected and the de-ionised water from a water-tank was supplied uniformly from a droplet applicator on the top of the column. The droplet applicator was made from 10 cotton wicks. The water moved through these wicks by capillary action and the droplets, which formed at the lower end, dropped over the entire surface. The valve at the bottom was opened to allow effluent to flow through the column, maintained by a small head of water on the surface. An in-line conductivity probe was attached to the drainpipe and this was connected to a data-logger via an EC meter for continuous monitoring of the EC of the effluent (Fig. 1).

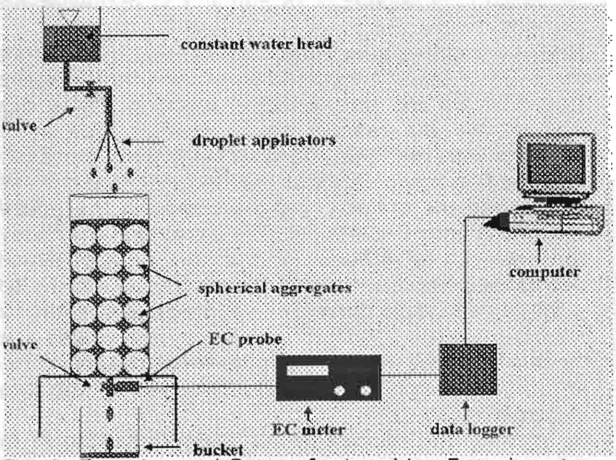

Fig. 1: Experimental Set up for Leaching Experiments

The water flux entering the cylinder and draining out of it were set equal with the help of controlling valves. Water flowed continuously through the column so that the aggregates were surrounded all the time by the flowing fresh water. The experiments were performed at a temperature of 25 ± 1°C. The effluent was collected in a bucket and the volume was measured. Flux densities of 5.3 mm/min and 13 mm/min were used in these experiments for investigating the effect of flux density on the leaching. Experimental conditions used in the continuous leaching experiments are given in Table 1.

Table 1: Continuous Leaching Experimental Conditions

Aggregate diameter (mm)	No. of aggregates used in column	$\beta = V_B/V_A$	Porosity of aggregates (mm^3/mm^3)	Interstitial porosity* (mm^3/mm^3)
8	2250	2.82	0.31	0.47
16	276	2.49	0.40	0.49
31	41	2.14	0.38	0.45

* Interstitial porosity = madrepore volume/total volume of the column.

In the case of intermittent leaching columns similar to those used in the continuous leaching experiments were prepared and the same leaching procedure was followed except that during leaching the outflow from the column was regularly interrupted using the outflow control valve according to the times of *on* and *rest* periods. During the *rest* periods, the macropores were kept saturated. All continuous and intermittent leaching experiments were replicated three times. Table 2 shows the experimental conditions used for intermittent leaching.

Table 2: Experimental Conditions for Intermittent Leaching

Aggregate diameter (mm)	No. of aggregates used in column	$\beta = V_B/V_A$	On period (min)	Rest period (min)
8	2250	2.82	15	30
16	276	2.49	15	15 and 30
31	41	2.14	15	30

Results of Continuous and Intermittent Leaching

(a)continuous Leaching: Fig. 2 shows the mean relative solute concentration of the effluent plotted against the time of leaching when columns of three different aggregate sizes were leached continuously with a flux density of 5.3 mm/min. This shows that for all aggregate sizes, the mean relative concentration of the effluent initially increased rapidly but then started decreasing quickly. Similar trend in EC of leachate was observed by Tanton *et al.* (1988a and 1990) during their field leaching experiments in Turkey. The most rapid increase and decrease in relative solute concentration were observed in aggregates of size 8 mm followed by the 16 mm and 30 mm sizes. The curves for all aggregates ended with extended tailings as the solute within aggregates continued to diffuse out slowly.

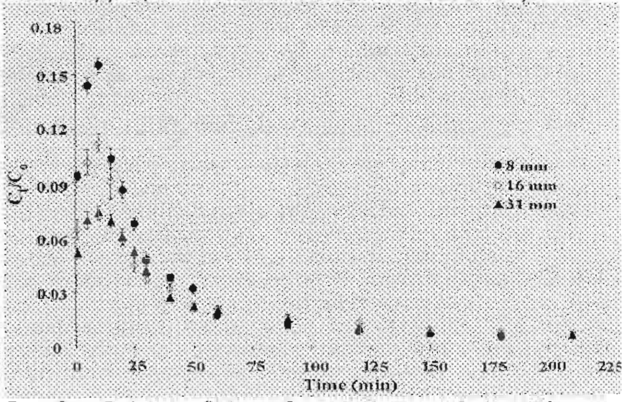

Fig. 2: Relative Solute Concentration of the Effluent Plotted Against Time of Leaching for Three Aggregate Sizes (Water Flux Density = 5.3 mm/min)

The lower relative solute concentration in the effluent results in a higher concentration gradient between the micro and macro pores right from the start of the leaching process. The concentration in the effluent after some time decreased so low that further leaching of the aggregates was stopped assuming that the aggregates were completely washed out. However, when the results of leaching were plotted as the relative solute mass remaining in the column against the number of pore volumes (madrepore volume in column) of water applied for leaching; the results showed that the aggregates of size 31 mm still had more than 38% of the solutes at the end of the leaching process as shown in Fig. 3.

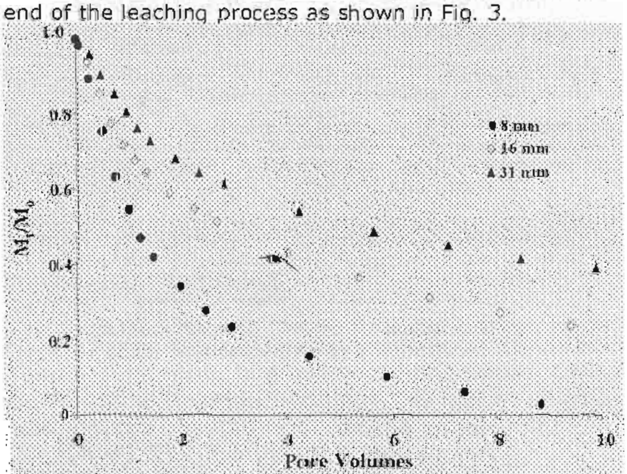

Fig. 3: Relative Solute Mass Remaining in Columns Plotted Against Number of Pore Volumes of Water Used for Leaching (Aggregate Sizes 8 Mm, 16 Mm and 31 mm, Water Flux Density 5.3 mm/min)

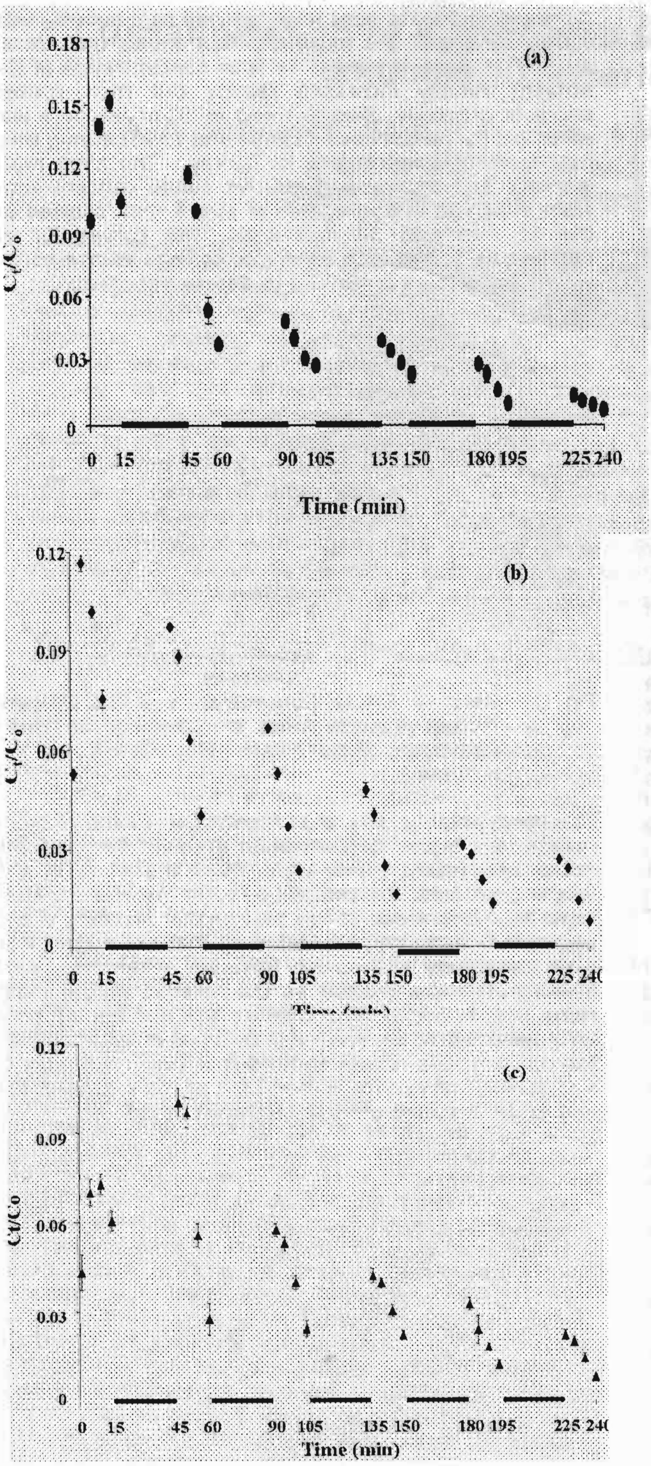

Fig. 4: Relative Solute Concentration in the Effluent Plotted Against Total Time of Leaching (Water Flux Density 5.3 Mm/min, Rest Periods = 30 Minutes). Aggregate Size (A) 8 mm (B) 16 mm and (C) 31 mm. Thick Lines on the X-axis represent rest periods during leaching

This shows that solute from the aggregates of size 8 mm leached faster, followed by the aggregates of sizes 16 mm and 31 mm. After the drainage of 8 pore volumes of water, 96% of the salts were leached from a column of aggregates of size 8 mm, while the salts leached from columns of aggregates of 16 mm and 31 mm were 72% and 60% respectively.

(b)Intermittent Leaching: Fig. 4 shows the results of the relative solute concentration in the effluent against total time (*on* and *rest* period) of leaching. These show that initially the relative solute concentration in the effluents increased but afterwards it started decreasing until the first *rest* period was reached. At the end of each *rest* period there was a rapid increase in the relative concentration of the effluent. The increase in the relative concentration of effluent at the end of *rest* periods decreased progressively with the successive *rest* periods with the most rapid decrease in aggregates of small size followed by the medium and large aggregates. The highest increase in the relative concentration of the effluent after *rest* periods was observed in the large aggregates (31 mm).

By plotting the relative solute mass remaining in the columns against the number of pore volumes of water used in leaching aggregates in Fig. 5 it can be seen that the column containing the smaller aggregates (8 mm) leached the fastest followed by the medium size aggregates (16 mm) and the large aggregates (31 mm). After the drainage of 4 pore volumes, the solute mass leached from columns of aggregates of 8 mm, 16 mm and 31 mm was 84%, 66% and 55% respectively.

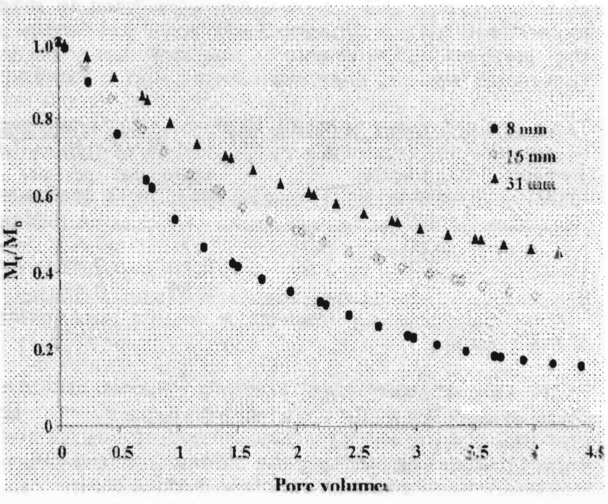

Fig. 5: Relative Solute Mass Remaining in the Columns Plotted Against the Number of Pore Volumes of Water Used (Water Flux Density 5.3 mm/min and Aggregate Sizes 8 Mm, 16 mm and 31 mm)

Effect of Flux Density on the Rate of Leaching: To determine the effect of flux density under continuous leaching the aggregates of size 16 mm were also leached with flux density of 13 mm/min. The results of leaching are plotted as relative solute mass remaining in the column against pore volumes of water used in leaching and are shown in Fig. 6. The Fig. shows that flux density of 5.3 mm/min leaches more solute than the flux density of 13 mm/min under continuous leaching because it provides time for solute diffusion from micro to macro pores.

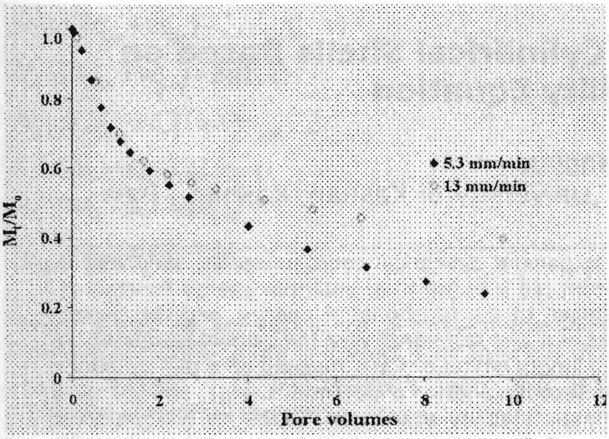

Fig. 6: Relative Solute Mass Remaining in the Column Plotted Against Pore Volumes to Show the Effect of the Flux Density on the Leaching During Continuous Leaching (Aggregate Size 16 mm)

Comparison of Continuous Leaching with Intermittent Leaching: The comparison of continuous leaching with intermittent leaching, in terms of water required, for leaching 60% of the salts is summarized in Table 3. Table shows 40% water savings with intermittent leaching for large aggregates with flux density of 5.3 mm/min. However, with increasing flux density the advantage of using intermittent leaching increased. The results showed that for leaching 60% of the salts from aggregates of size 16 mm with a water flux density of 13 mm/min, continuous leaching required 9.8 pore volumes as compared to 3.4 pore volumes needed for intermittent leaching. Thus water savings of up to 65% were possible with intermittent leaching with flux density of 13 mm/min.

Table 3: water Used for Leaching 60% of the Salts with Continuous and Intermittent Leaching with Flux Density 5.3 mm/min

Aggregate diameter (mm)	Continuos leaching (pore volumes)	Intermittent leaching (pore volumes)	%age of water savings
8	1.58	1.50	12
16	4.70	3.13	34
31	9.40	5.60	40

Recommendations

- Use intermittent leaching instead of continuous leaching if there is shortage of water. Our results showed that under laboratory conditions water savings up to 65% are possible with intermittent leaching.
- If using intermittent method then leaching process should be carried out during winter so as to minimize water losses due to intensive evaporation.
- Use tillage to produce small aggregates as salt diffuses quicker from the small aggregates. Also small aggregates reduce madrepore flow thus minimizing water losses due to by madrepore flow.

Results and Discussion

As in our experiments macro pores of the column were initially empty while the microforms within the aggregates were saturated with solute, therefore diffusion was dominant feature right from start of the leaching process. There was an initial rapid increase in the concentration of the effluent followed by a gradual decrease. This may be because when the column was filled with water from the bottom of the column, the solute started to diffuse out, resulting in a uniform increase in the concentration of solution in the macro pores. When the water was applied from the top of the column, the solution started moving down through the column and due to diffusion of the solute from the aggregates, its concentration also increased with the depth of column. Later the concentration gradient between macro and microforms slowly decreased, causing a slower diffusion of solute from the microforms resulting in a gradual decrease in the concentration. Aggregate size determines the mean diffusion path length (Rao *et al.* 1980b), which means the larger the aggregate size, the longer the diffusion pathways. Therefore, the solute in the center of the aggregate has to cover a longer distance to reach the macro pores where it is leached. For the same column and flux density more time is available for the solute to diffuse out of the small aggregates. Experimental results also supported the above theory and showed that 1.58 pore volumes of the water were used for leaching 60% of the solute from the small aggregates compared to 9.4 pore volumes used by large aggregates. The leaching of columns intermittently provided more time for the solute in the microforms to diffuse out into macro pores during the *rest* periods, resulting in an abrupt increase in the concentration of the effluent after each *rest* period. The results showed that at small flux densities, the overall benefit of using intermittent leaching was small because then there was ample time for diffusion during the *on* period. This is consistent with the field observations of Verma and Gupta (1989) who found a marginal decrease in the soil salinity with intermittent leaching over continuous leaching for their clay soil, that had low hydraulic conductivity. However with the higher flux density (13 mm/min), the results showed that for leaching 60% of the salts from aggregates of size 16 mm, water savings of 65% were possible by using intermittent leaching over continuous leaching.

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