Study of salt removal with evaporation drainage method

M.M. Abu-Zreig[1]*, Y. Abe[2] and H. Isoda[2]

[1]*Department of Biosystems Engineering, Jordan University of Science and Technology, P.O.Box 3030, Irbid, Jordan; and* [2]*Allied for Research in North Africa, University of Tsukuba 1-1-1, Tennodai, Tsukuba, Ibaraki 305-8572, Japan. *Email: majed@just.edu.jo*

Abu-Zreig, M.M., Abe, Y. and Isoda, H. 2006. **Study of salt removal with evaporation drainage method**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **48**: 1.25 - 1.30. Soil drainage and reclamation is often achieved by soil leaching with fresh water. However, soil leaching is limited by land conditions and the availability of fresh water. A new method called Evaporation Drainage Method that removes excess water and salts through evaporation from fabric columns, called accelerators, installed in the soil or saline water. Laboratory experiments were conducted to examine the influence of accelerator length and diameter and salt concentration on water drainage through evaporation and on salt removal. Accelerators with 8 lengths ranging from 60 to 300 mm and 4 diameters ranging from 5 to 30 mm were used. Five saline solutions prepared by mixing KCl with water at 1, 3, 5, 7, and 10% by weight were used in the experiments. Experimental results showed that accelerators significantly increased water evaporation and salt removal from ponded solution and this increase is directly related to length and diameter of accelerator, and to a lesser degree, salt concentration. A 60-mm long accelerator increased water evaporation by 27% and a 300-mm long accelerator by 100% compared to pan evaporation. A 300-mm accelerator increased salt removal by about 320% compared to the 60-mm long accelerator. Increasing the diameter of the accelerator from 5 to 30 mm increased evaporation rate and therefore salt removal by 160%. High salt concentration slightly reduced evaporation compared to low concentration but increased salt removal from solutions. The total salt removal by a 300-mm long accelerator in a 1% KCl solution was 1.2 g compared to 28 g in a 10% KCl solution representing about 13 and 30% of the total salt in the solution, respectively. **Keywords:** saline solution, drainage, evaporation enhancement, capillary flow.

Le drainage et la mise en valeur des sols sont souvent réalisés par le lessivage à l'aide d'eau douce. Cependant, le lessivage de sols est limité par les conditions du sol et la disponibilité d'eau douce. Une nouvelle méthode appelée méthode de drainage par évaporation retire l'excès d'eau et de sels par l'évaporation en colonnes de tissus, appelées accélérateurs, installées dans les sols ou les eaux salées. Des expériences en laboratoire ont été réalisées pour examiner les influences de la longueur de l'accélérateur et de son diamètre ainsi que la concentration en sels sur le drainage de l'eau par évaporation et l'extraction de sels. Des accélérateurs de huit longueurs différentes variant de 60 à 300 mm et de quatre diamètres variant de 5 à 30 mm ont été utilisés. Cinq solutions saline préparées en mélangeant du KCl avec de l'eau à 1, 3, 5, 7 et 10% sur une base massique ont été utilisées pour les expériences. Les résultats expérimentaux ont démontré que les accélérateurs augmentent significativement l'évaporation de l'eau et l'extraction du sel d'une solution en bassin et que ces augmentations étaient directement reliées à la longueur et au diamètre de l'accélérateur ainsi, quoiqu'à un niveau moindre, à la concentration. Un accélérateur de 60 mm de longueur augmentait l'évaporation de l'eau de 27% et un accélérateur de 300 mm de longueur augmentait l'évaporation de 100% comparativement à l'évaporation de référence du bac. Un accélérateur de 300 mm augmentait l'extraction de sel d'environ 320% comparativement à un accélérateur de 60 mm de longueur. Une augmentation du diamètre de 5 à 30 mm augmentait le taux d'évaporation et par le fait même l'extraction de sel de 160%. Une concentration élevée de sel réduisait légèrement l'évaporation comparativement à de faibles concentrations mais augmentait l'extraction du sel des solutions. Le sel total extrait par un accélérateur de 300 mm de longueur dans une solution de KCl à 1% était de 1,2 g comparativement à 28 g dans une solution de KCl à 10% représentant respectivement environ 13 et 30% du sel total en solution. **Mots clés**: solution saline, drainage, évaporation accélérée, écoulement capillaire.

INTRODUCTION

Soil salinization and water logging are major problems affecting agricultural production in the world. A report published by the Food and Agricultural Organization estimated that salinization affects about 20 to 30 million hectares of the world's 260 million hectares of irrigated land (FAO 2000). Adequate drainage of the soil is essential to maintain favorable soil-water conditions for optimal crop growth and to control soil salinity, especially in arid and semiarid lands.

Soil leaching is believed to be the only practical way to reduce excessive soluble salts from soils. It can be achieved by applying low-salinity water to soil. The water percolates through the active root zone depth of the soil carrying away salts. Leaching requires installation of a subsurface drainage system if no natural drainage pathway is present and is limited by land topography and soil characteristics. Leaching of clayey soil can be difficult since most drainage water in cracking clay soils travels through macropores and does not interact with the soil matrix, (Bouma 1980; Singh and Kanwar 1991). During leaching, salt contained in the water within the microspores may be considered to be immobile and cannot be removed from the soil profile (Hutson and Wagenet 1995; Tanton et al. 1988).

Despite the apparent simplicity of the soil-leaching method, it requires thorough investigations on soil and water characteristics to determine the optimum depth of leaching water. Soil leaching can be expensive and time consuming. Furthermore, soil leaching necessitates the availability of high quality irrigation water for leaching which can be a limiting factor in arid and semi arid lands. A new drainage method that overcomes the limitations of the leaching method is being investigated. This method is called Evaporation Drainage Method (EDM).

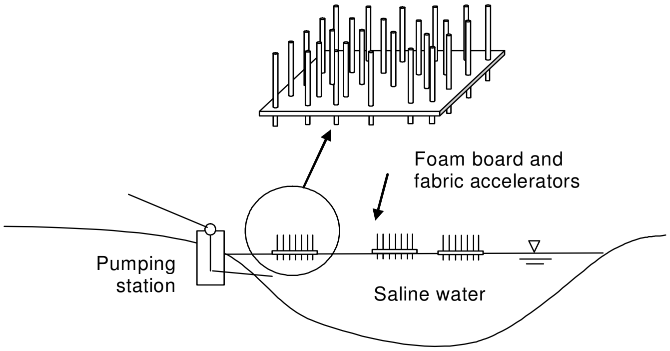

Fig. 1. Schematic diagram to envisage the possible use of Evaporation Drainage Method for reclamation of saline drainage water.

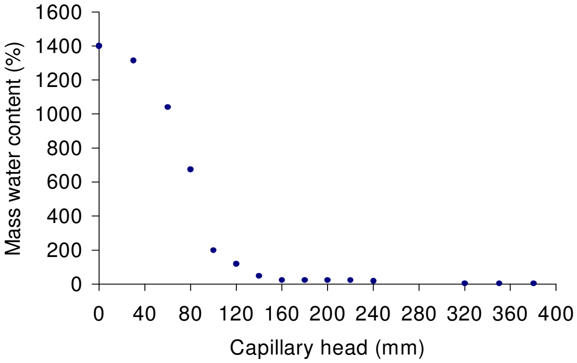

Fig. 2. Moisture distribution with capillary head for the accelerator fabric.

The Evaporation Drainage Method has been investigated by researchers at the University of Tsukuba (Abe et al. 1995). The concept of EDM is to remove excess water and salt from saline and water logged soil by evaporation taking advantage of the strong evaporation potential in arid and semi-arid climates. Evaporation is enhanced by fabric columns made of highly absorbent materials, called accelerators, that are inserted in water or water logged soil. Accelerators absorb water by capillary action and increased exposed wetted surface area and enhanced evaporation. Accelerators also absorb soluble salts that precipitate on their surface during the evaporation process. The EDM method permits the use of moderate salinity water for soil reclamation since accelerators enhance removal of salts from leached solution. Therefore, EDM can be useful in arid and semi-arid areas where the saline problem is serious and water resources are scarce.

Field application of this method has not been addressed in the literature. Wide scale application on water-logged soil may be achieved by manufacturing thin boards of foam through which accelerators with certain length can be installed at specific intervals. These pre-manufactured foam boards can be readily transported and placed on ponded saline water or inserted in water-logged soil. Saline soil may be leached by poor quality water to dissolve salt from the soil profile then drainage water is treated by EDM. The effectiveness of EDM in soil may be limited due to the difficulty of inserting the wicks in the soil profile and the need for long wicks to keep contact with the declining soil water level. However, the application of EDM for reclamation of saline drainage water is promising. Foam boards float on the water surface and ensure continuous contact with the water body. When the salinity of drainage water is acceptable, it can be reused for irrigation and leaching. A schematic diagram for such application on the field is shown in Fig. 1. The associated cost with this procedure may hinder its use in the field but this depends on the cost of materials. Nevertheless, EDM can be cost effective especially in arid countries where water is scarce.

A few studies have examined the influence of accelerators on evaporation and salt removal under laboratory conditions (Abe et al. 1995; Ogawa et al. 1998; Zhu et al. 2005). The concept of water drainage with evaporation enhancement by accelerator was first introduced by Abe et al. (1995). Ogawa et al. (1998) studied the influence of accelerator shape and type of fabric on the evaporation rate from water. They found that round accelerators were most effective in evaporation enhancement among three other shapes that were tested (single piece of high absorptive paper, fan with various number of sheet leafs and cylindrical shape). Zhu et al. (2005) found that accelerator length is the most important factor affecting the evaporation rate from water. They also reported that installing a removable ring, called a cap, on the accelerator can enhance evaporation and salt removal efficiency by 30%. However, no systematic studies have been conducted to quantify the salt-removal efficiency of accelerators with different lengths and diameters. In addition, the influence of salt concentration on evaporation and salt removal efficiency has not been investigated because previous studies were limited to one salt concentration.

The objectives of this paper were to examine the influence of accelerator diameter and length and salt concentration on the evaporation and salt removal rates from saline solution.

MATERIALS and METHODS

Laboratory experiments were conducted to quantify the influence of various accelerator and solution properties on evaporation and salt removal rates from a saline solution. The accelerators used in the experiments were of cylindrical shape made of highly absorptive cooking paper (Lion Corporation Ltd., Tokyo, Japan). The cooking paper is made of rolls of connected sheets having a dimension of 280 x 200 mm. The thickness of the paper was 0.8 mm with bulk density of about 5.77 kg/m^3. The saturated mass-basis water content was 1400%.

The moisture distribution of the cooking paper was measured by conducting a capillary rise experiment. Four connected sheets were rolled over a steel wire of 2-mm diameter to make a wick of fabric 400 mm long. The wick was submerged in a blue dyed-water to a depth of 20 mm and the water rise in the fabric wick was monitored until the advance of the wetting front was negligible. The wick was cut into 20 mm-long pieces and the water content of each strip was measured. The moisture distribution with capillary head is shown in Fig. 2.

The variables studied in this research were salt concentration and length and diameter of accelerator. Synthetic

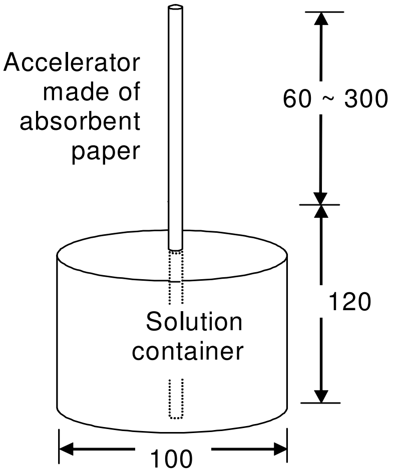

Fig. 3. **Experimental setup showing the container and the accelerator. Dimensions in millimeters.**

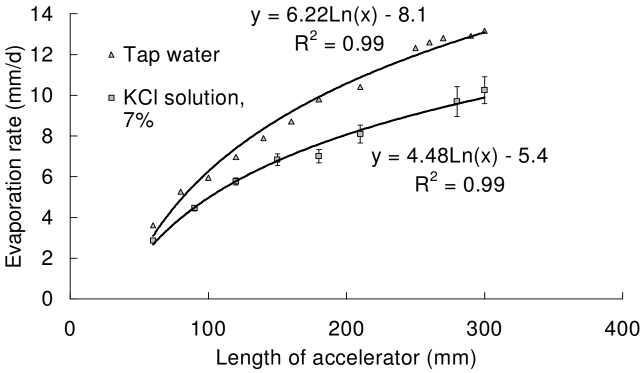

Fig. 4. **Influence of accelerator length on evaporation rate from tap water and saline solution of 7% KCl concentration during seven days. Bar represents data range. The diameter of the accelerators was 12 mm.**

saline solution made of five KCl concentrations varying from 1 to 10% by weight were used to examine the influence of salt concentration on the evaporation rate and salt removal rates from saline solutions in the presence of accelerators. The KCl salt was used as a model saline solution because K$^+$ ions have lower mobility in solution and higher absorption characteristics compared to Na$^+$ making the experimental results more expressive. The K$^+$ ion has a smaller radius of hydration and smaller hydration energy compared to Na$^+$. Nevertheless, future tests involving soil will be conducted with NaCl solution because NaCl is a major salt in saline agricultural soil. Eight accelerator evaporative lengths ranging from 60 to 300 mm and diameters of 5, 12, 20, and 30 mm were used to examine their influence on the evaporation rate and salt removal from saline solutions.

Tap water or saline solution was placed in a water container, 120 mm high and 100 mm inside diameter, with a plastic cover that prevented direct evaporation from the water surface. A hole was made in the cover of the container in which one accelerator of specific length and diameter was inserted to a depth of 100 mm below the water surface; this distance is called the absorptive length while the height of accelerator above the water surface was called the evaporative length. The experimental setup is shown in Fig. 3.

The container, filled with water or saline solution, was placed in a closed computerized chamber of about 175-L capacity to monitor evaporation rate under constant climatic conditions. The inside temperature, relative humidity, and wind velocity were kept constant by a digital controller at 40°C, 30%, and 1.5m/s, respectively, resulting in a pan evaporation rate of 10.4 mm/d. The wind speed, inside the chamber in which the water container was placed, was generated by adjusting the rotating speed of a circular disk of 500 mm in diameter. The evaporation rates were recorded over time by measuring the weight loss of the container at various time intervals. The salt removal rates by the accelerator were monitored by measuring changes in the electrical conductivity of the saline solution every 24 h. The salt concentration and water level in the container were adjusted daily by adding a certain amount of salt and water equal to that absorbed or evaporated during the previous 24 h. At the end of experiments with salt, the total salt accumulated on the accelerator was recorded by measuring the final and initial dry weight of the accelerator. All experiments were continued for one week.

RESULTS and DISCUSSION

Effect of accelerator length on evaporation

Figure 4 shows the influence of the accelerator length, for 12-mm diameter, on evaporation from tap water and 7% KCl solution under constant temperature and humidity and covered water surface. Water evaporation rate increased from 3.5 to as high as 13 mm/d as the length of accelerators increased from 60 to 300 mm, respectively (270% increase). The corresponding increase in the case of saline solution was 230%. The evaporation rates in the case of a 30 mm long accelerator correspond to about 130 and 100% of direct evaporation rate from water surface which was equal to 10.4 mm/day, for water and saline solution, respectively. The lower evaporation rate in the case of saline solution was due to the accumulation of salts on the surface of accelerators during the evaporation process (Ohtsuka et al. 1995). Evaporation variations in the case of saline solution have been recorded, as shown by the vertical bars in Fig. 4; whereas no variation in evaporation was observed in the case of tap water.

The evaporation rates increased rapidly with added length for short filters, then increased less for long filters. A logarithmic function seemed to fit the data very well with R^2 = 0.98. Extrapolating the equation to shorter lengths will result in lengths less than 35 mm that will have zero evaporation indicating a changing relationship for short accelerators. This is due to the existence of a boundary layer near the container cover. This result can be explained using the capillary rise theory (Hanks and Ashcroft 1982). The evaporation rates are expected to increase with length logarithmically as long as the length of accelerator remains below the equilibrium capillary rise of the fabric. As accelerator length approaches the equilibrium capillary rise of the materials, the evaporation rate decreases accordingly. No increase in evaporation is expected when the accelerator length exceeds the equilibrium capillary rise of the accelerator's material. The equilibrium capillary rise

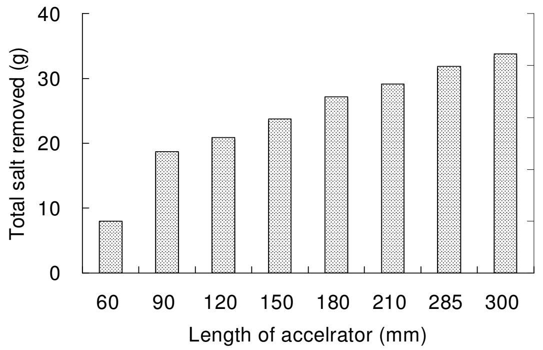

Fig 5. Salt removal in grams and as a percentage of the total salts in the solution container in a 7-day period as affected by length of accelerator. KCl concentration = 7%; diameter of accelerators = 12 mm.

of the materials used in the present experiments seemed to be 300 mm; accordingly only a small increase in evaporation was observed when accelerator length approached 300 mm.

Salt removal with accelerator

The strong influence of accelerators on evaporation rate may be utilized for salt removal from saline solution. The influence of accelerator length on salt removal from 7% KCl saline solution is shown in Fig. 5. Fabric accelerators were very effective in removing salt from a saline solution. As the length of accelerator increased from 60 to 300 mm the amount of salt removed during the entire duration of the experiment, 7 d, were 8 and 33 g, respectively, representing about 12 and 51% of the total salt mass in the solution. However, the salt removal rates decreased with time. Figure 6 shows the salt removal rates during each of the 7 days for a 300 mm long accelerator. As shown in the figure, the amount of salt removed in the first day was about 13 g, representing about 38% of the total salt removed and decreased sharply in the second day to reach only 4 g or13%. The decrease in salt removal continued at a much slower rate to reach 9% during the seventh day of the experiment. This is due to the changing of evaporating power of the accelerator with time due to the continuous accumulation of salt on its surface. However, accelerator properties seemed to reach a steady sate after day 1 resulting in a relatively constant salt removal thereafter.

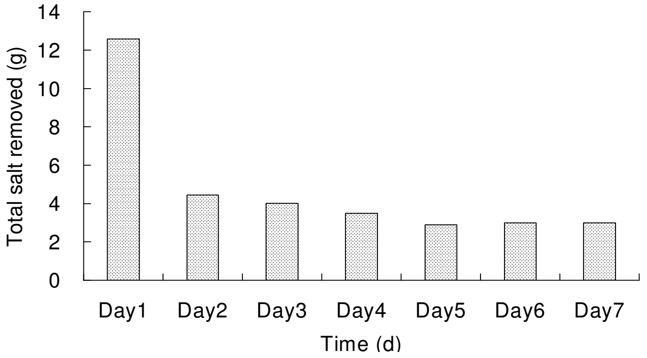

Fig. 6. Total salt removal in each day of a 7-day experiment. Length of accelerator = 300 mm; diameter = 12 mm; and KCl concentration = 7%.

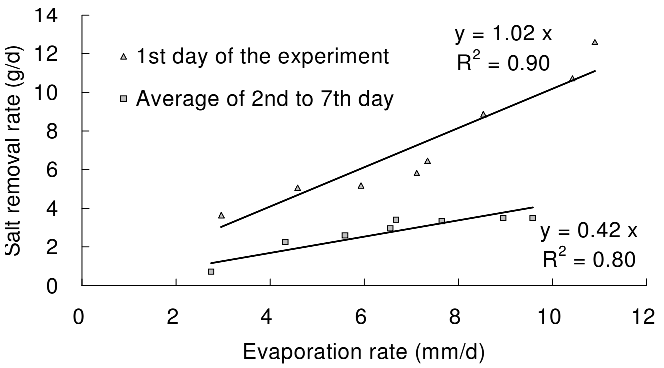

Fig. 7. Relationship between the average salt removal rate and evaporation rate in the first and subsequent second to seventh day of the experiment. KCl concentration = 7%; accelerator diameter = 12 mm.

Salt removal by accelerators is directly proportional to the evaporation rate. Increasing the length of accelerator up to 300 mm increased the evaporation rate from solution and therefore increased the salt removal rate. Figure 7 shows the relationship between salt removal and evaporation rate during the first and during the second to seventh day of the experiment because the accelerator's properties remained constant during these periods. A linear relationship was found between salt removal rate (g/d) and evaporation rate (mm/d) during the fist day of the experiment with a slope of 1.0 and coefficient of determination $R^2 = 0.90$. However the influence of evaporation on salt removal in the subsequent days, day 2 to day 7, was much weaker than that in the first day with a slope of 0.42 and $R^2 = 0.8$, shown in Fig. 7. The decrease in salt removal rates with time is due to the accumulation of salt that was removed from the solution on the accelerator surface. Salt accumulation reduced the amount of upward flow and decreased evaporation thus reducing salt removal. Similar results were also reported by Zhu et al. (2005). They found that the evaporation rate of saline solution in the presence of a 180 mm long accelerator was smaller than that for tap water.

Effect of accelerator's diameter on evaporation rate

It was hypothesized that increasing the diameter of the accelerator could increase evaporation rate from the solution and therefore increase the salt removal. Figure 8 shows the influence of accelerator diameter on evaporation rate for a 180 mm long accelerator. A direct and linear relationship was found between evaporation rate and diameter with a high R^2 of 0.98. Increasing the diameter of accelerator from 5 to 30 mm resulted in a 120% increase in the evaporation rate, from 6 to 16 mm/day. Interpreted from Fig. 6, the expected increase in salt removal for the first day would also be 120%. The increase in the accelerator diameter increased the upward capillary flow resulting in an increase in the evaporation rates. However, the relative increase in the evaporation rate with respect to the amount of fabric used in accelerators seemed unjustified. The amount of fabric used in an accelerator of 30 mm in diameter is 16 times that for a 5-mm accelerator.

Salt removal rate as affected by salt concentration

Figure 9 shows the total salt removal of a 180-mm long accelerator as affected by solution concentration. At 1%

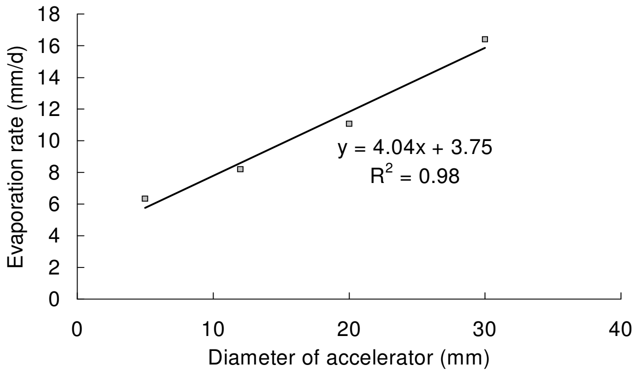

Fig. 8. The influence of accelerator diameter on the evaporation rate of tap water. The length of the accelerator = 180 mm.

solution, about 1.2 g of salt was removed by the accelerator and increased to 13 g for the 5% solution, 26.9 g for the 7% solution, and 28.5 g for the 10% solution. The amount of salt removed increased rapidly with solution strength up to 7% then increased only a little for higher concentration of 10% solution. Indeed, the salt removal percentage from the total salt in the container was 42% for the 7% solution compared to only 30% for the 10% solution, as shown in Fig. 9.

The increase in salt removal with salt concentration is logical since the upward flow through the accelerator contains more salt for higher concentration solution and this salt eventually precipitates on the surface of the accelerator after evaporation. However, at concentrations higher than 7%, the salt precipitation on the surface of accelerators seemed to hinder evaporation rate and therefore salt removal. This is shown in Fig. 10 where the evaporation rate in the case of 10% solution was the lowest among all other solutions. Although all solutions showed a decrease in the evaporation rate with time, the 10% solution had the largest decrease and largest slope.

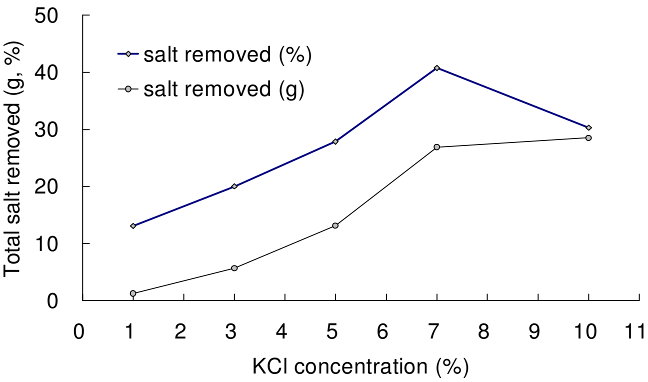

Fig. 9. Total salt removed, in grams and percentage of total salt in the solution container, as affected by the salt concentration of the solution. The length and diameter of the accelerator were 300 and 12 mm, respectively.

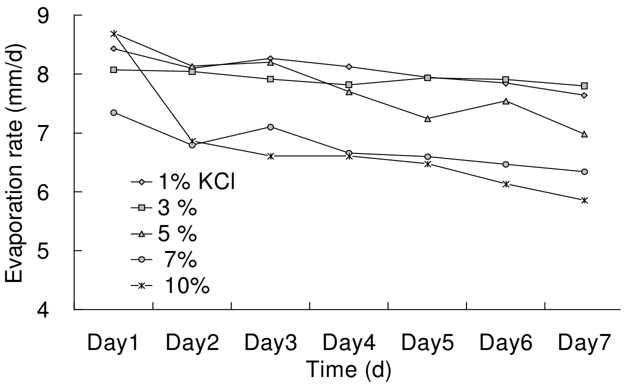

Fig. 10. Variation of evaporation rates for various concentrations of KCl with time. The length and diameter of the accelerator were 180 and 12 mm, respectively.

CONCLUSION

Application of fabric columns for removal of salts from saline water is promising. Installing accelerators in saline water enhanced evaporation rate and removed salt through upward capillary flow and the subsequent salt precipitation on the surface of the accelerators. The efficiency of an accelerator in enhancing evaporation rate and salt removal is highly affected by its length and, to a lesser degree, its diameter. Increasing the length of accelerator from 60 to 300 mm increased the evaporation rate of saline solution from 3 to 10 mm/d and salt removal from 10 to 42% of the total salt in the solution. Salt removal by accelerator is directly proportional to solution salinity up to 7% concentration due to the higher amount of salt in the upward flow through the accelerator. At salt concentration of 10% the percentage of salt removal increased a little to 30% of the total salt in the solution, compared to 42% in the 7% KCl solution.

Thorough research is still needed to assess the applicability of EDM under field conditions and to determine the number of accelerators needed per square meter, the replacement rate, the required insertion depth into the soil, and the influence of soil moisture and texture on the performance of EDM. Results presented here show that an accelerator of 300 mm evaporative length and densities of 80 per square meter can remove more than 40% of the salt from ponded saline water in seven days. An absorption length of 100 mm below the water surface was adequate for salt removal but preliminary experiments showed that a shorter absorption length up to 60 mm was sufficient. Dried accumulated salts on the accelerator's surface can be removed by shaking. Research is being conducted under laboratory conditions to assess the performance of this method on soil as affected by soil moisture and texture.

REFERENCES

Abe,Y., J. Tsurui, T. Yamaguchi, Y. Ohtsuka and H. Ii. 1995. Evaporation effect of a salt capturing stick and its influence on movement of solution and solute in soil. *Journal of Arid*

Land Studies (5): 43-54.

Bouma, J. 1980. Field measurement of soil hydraulic properties characterizing water movement through swelling clay soils. *Journal of Hydrology* 45: 149-158.

FAO. 2000. Land resource potential and constraints at regional and country levels. World Soil Resources Reports 90. Rome, Italy: FAO, Land and Water Development Division.

Hanks, R.J. and G.L. Ashcroft. 1982. *Applied Soil Physics.* Tokyo, Japan: Spring –Verlag.

Hutson, J.L. and R.J. Wagenet. 1995. A multiregional model describing water flow and solute transport in heterogeneous soils. *Soil Science Society America Journal* (59): 743-751.

Ogawa, T., Y. Abe, T. Yamaguchi, M. Ozaki and S. Yabashi. 1998. Excess water disposal using evaporation accelerators. *Journal of Arid Land Studies* (7): 261-264.

Ohtsuka, H., T. Ogawa, Y. Abe and T. Yamaguchi. 1995. Tracing the movement during evaporation of salt water through a sand layer and coiled paper core using three different anions as tracers. *Journal of Arid Land Studies* (5):33-42.

Singh, P. and R.S. Kanwar. 1991. Preferential solute transport through macropores in large undisturbed saturated soil columns. *Journal of Environmental Quality* (20):295-300.

Tanton T.W., A.S.B. Armstrong and D.W. Rycroft. 1988. The leaching of salts from restructured saline clay soils. *Soil Use and Management* (4):139-143.

Zhu G., Y. Abe and M. Abu-Zreig. 2005. Evaporation enhancement and salt removal by accelerators in evaporation drainage method. *Journal of Arid Land Studies* (15): 9-18.