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Hydrodynamic parameters of soluble salts transfer in soils case of the Ourlana palm grove, Algeria

Djihad Harkati[a, *], Noureddine Meza[b, c], Ahmed Ouamane[a] and Abdelkader Khiari[b]

[a]*Department of Civil and Hydraulic Engineering, Faculty of Science and Technology, Laboratory of Hydraulic planning and Environment (LAHE), University of Biskra, Algeria.*
[b]*Department of Urban Technical Management, Laboratory of natural resources and management of sensitive environments (RNAMS), University of Oum El Bouaghi, Algeria.*
[c]*Department of Geology, faculty of earth sciences and architecture, Laboratory of natural resources and management of sensitive eenvironments (RNAMS), University of Oum El Bouaghi, Algeria.*
E-mails : mezanour@yahoo.fr & hhkhiari@yahoo.fr & aouamane@yahoo.fr
[*] Corresponding author: email: *harkatidji@hotmail.com*

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Abstract:
In arid areas, reclaimed lands suffer from a major problem of secondary soil salinity, due to a bad water resources management and the presence of a shallow water table. In order to determine the amount of water that required to the leaching of the soluble salts, mathematical models of soluble salts transfer in soil based on the convection-diffusion equation are used. The reliability and effectiveness of the solutions of these mathematical models problems depend particularly on the precision of the experimental determination of the hydrodynamic parameters D^*, λ *and* v. *The purpose of this study is the experimental determination of the hydrodynamic parameters of soluble salts transfer in soil, the case of the palm grove of Ourlana. For this, large and small PVC columns with a diameter of 20 cm were used. Analysis of the results shows a difference between the results of* D^* *of large columns and small columns. They vary for the large columns in the range of [0.029 to 0.061* m^2/d*] and [0.004 to0.02* m^2/d*] for the small columns. The knowledge of the hydrodynamic parameters gives the possibility of optimizing the quantities of leaching water and consequently to manage the salinization risk of irrigated lands.*

Keywords: *Arid areas; Salinity; Irrigation; Leaching; soil.*

1. Introduction

In the arid areas, reclaimed lands suffer from a major problem of secondary soil salinity caused by an imbalance of water and salt balances, due to a bad water resources management which has the consequence of limiting crop yields.

The amount of water required to leach soluble salts is an important process that governs the rehabilitation of saline soils [1,8, 23]. The practice in several countries in the world has shown to reach a complete desalinization; we use a very important volume of water, the example of: [5, 10, 11, 12]

- In Uzbekistan for the region of Bukhara, with a water table depth of 1m, leaching volume is 26000 m^3/ha, and with a water table depth of 1m, leaching volume is 8000 m^3/ha;

- In Iran for the region of Dadjallah, with a drain depth of 1.2 m, the leaching volume is 16000 to 17000 m^3/ha

- In Egypt for the Abyss region, for a drain Depth of 0.9 m, the leaching volume is 30000 to 34000 m^3/ha.

The salinization risk management of irrigated lands and the guarantee of a high and stable agricultural production are only possible by the predictions of soil soluble salts dynamic sat a depth corresponding to the vadose zone of soil i.e. an optimal leaching irrigation regime.

For this, mathematical models of soluble salts transfer in soil based on the convection-diffusion equation are used[1]. The reliability and effectiveness of the solutions of these problems depend particularly on the precision of the experimental determination of the hydrodynamic parameters. [1, 3, 23]

The principal objective of the present work is the experimental determination of the hydrodynamic parameters of soluble salts transfer in soil that involved in the convection-diffusion equation, in the Oued Righ valley case of the Ourlana palm grove.

2. Theoretical consideration

For a steady-state water flow in a saturated soil profile, the partial differential equation describing the distribution of the soluble salts concentration can be written as follows: [1,4,23]

$$R\frac{\partial C}{\partial t} = D^{*}\frac{\partial^{2} C}{\partial z^{2}} - v\frac{\partial C}{\partial z} - \frac{\partial N}{\partial t} \qquad (1)$$

Where: Ris the retardation factor.

$$R = 1 + \frac{\rho k}{\theta}$$

K is an empiricaldistribution coefficient. If there are no interactions between solute and soil (Cation exchange capacity CEC < 15 meq/100g)[16],$\mathbf{k}$ becomes null and $\mathbf{R} = 1$;$\boldsymbol{\rho}$ is the soil bulk density [ML^{-3}]; $\boldsymbol{\theta}$ is the total porosity [$M^{-3}L^{-3}$]. $\mathbf{C}$ is the concentration of soil solution salts [ML^{-3}]; $\mathbf{D^{*}}$ is the convection-diffusion coefficient [$L^{2}T^{-1}$] $\mathbf{D^{*}} = \boldsymbol{\lambda}\,\mathbf{v} + \mathbf{D_m}$; v is the pore-water velocity [LT^{-1}] ; $\boldsymbol{\lambda}$is the dispersivity [L] ; $\mathbf{D_m}$ is the molecular diffusion coefficient [$L^{2}T^{-1}$] ; $\mathbf{t}$ is the time [T] ; $\mathbf{z}$ is a spatial coordinate[L].$\frac{\partial N}{\partial t} = \boldsymbol{\gamma}(\mathbf{C_s} - \mathbf{C})$[22,23] ; $\mathbf{C_s}$ is the concentration of the maximum saturated soil solution [ML^{-3}], $\mathbf{C_s}$ =359 g/l for NaCl at a temperature of 18 C° [8]; $\boldsymbol{\gamma}$ is the dissolution rate coefficient of salt crystals [T^{-1}] $\gamma = \gamma_1 + \gamma_2\sqrt{v}$; $\boldsymbol{\gamma_1}$ and $\boldsymbol{\gamma_2}$ are constants depends on the physicochemical properties of the soil. In the Oued Righ valley soils (62% sand and CEC< 10 meq/100g) and under leaching experiment, which makes that$\mathbf{D_m} \ll \boldsymbol{\lambda}\mathbf{v}$ therefore $\mathbf{D_m}$ and $\boldsymbol{\gamma_1}$ can be neglected and

$\mathbf{D^{*}} = \boldsymbol{\lambda}\mathbf{v}$;[9]and$\boldsymbol{\gamma} = \gamma_2\sqrt{v}$. [1, 14, 23]

In the case of a soil column laboratory experiment applied to effluent curves, with a constant initial salinity, equation (1) has analytical solutions that allow calculating concentrations at an arbitrary depth (z) in an arbitrary time (t) considering the following initial and boundary conditions:[21, 24]

$$C(z, 0) = C0 = constant \qquad (t = 0)$$

$$D\frac{\partial C}{\partial z} = vC - v\,C_1 (z = 0)$$

$$\frac{\partial C}{\partial z}(L, t) = 0 (z \to L)$$

Where: $\mathbf{L}$ is the leached layer depth [L], $\mathbf{C_1}$ is the salts concentration in the irrigation water [ML^{-3}], and C_0 (z) is the initial salts concentration in soil [ML^{-3}].

3. Material and method

The study was carried out for a soil from the palm grove of Ourlana city of Djamaa (Latitude: 33°33'12N, Longitude: 5°59'51E) (fig. 1). The soil texture is loamy-sandy (62% sand, 24% loam, 14% clay) with the presence of salt crystals layer on the surface composed mainly of sodium chloride[18].

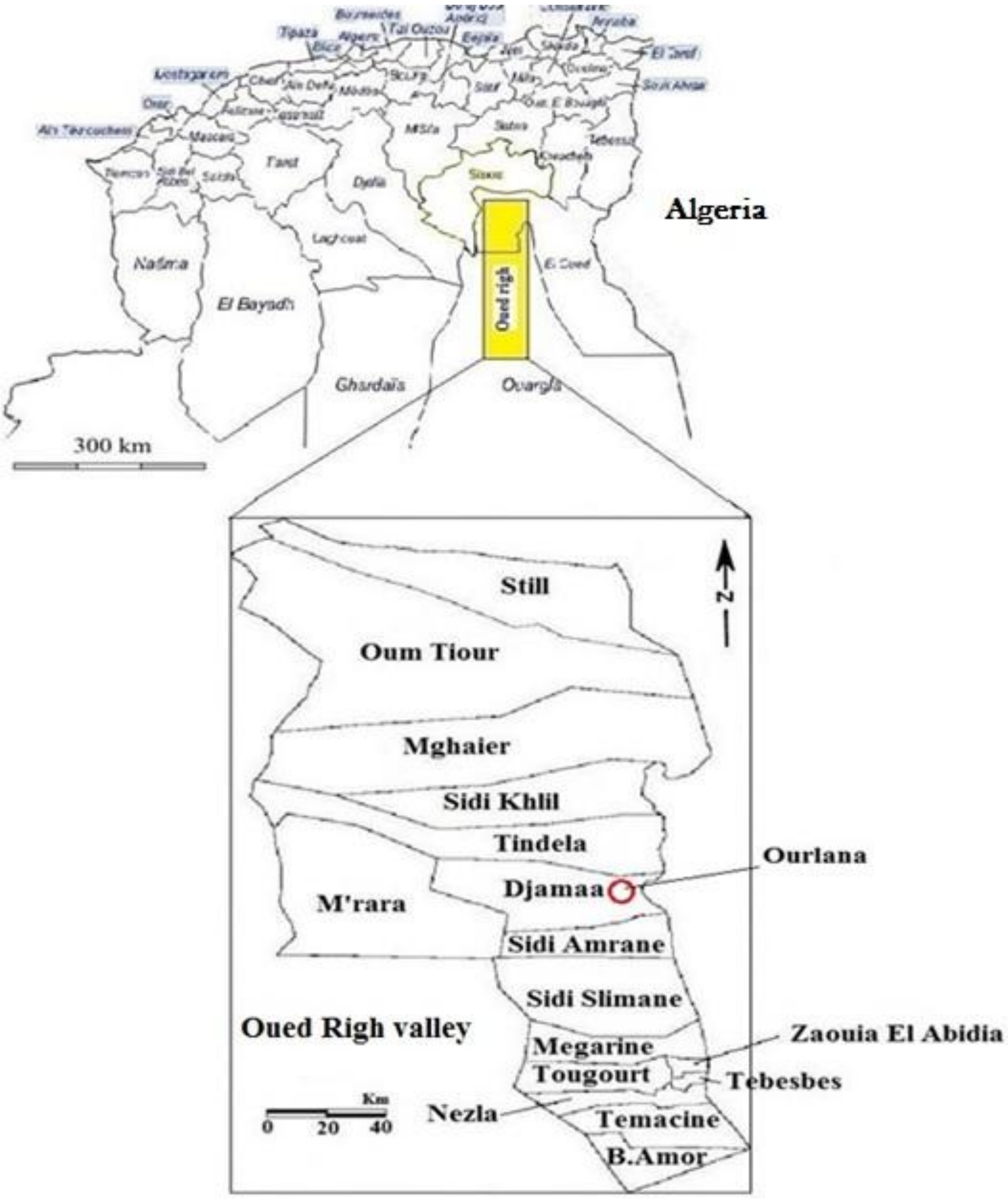

Figure1. Location of the Ourlana palm grove

The methodology for determining **D*** is released by observing the chloride ion (Cl^-) dynamics during leaching at the soil columns exit (fig.2)[7].

The experiments realization order is the following:

1- Three small PVC columns (Each layer represents a soil horizon with 0.20 m in internal diameter),and three large PVC columns (1 m high and 0.20 m in internal diameter) are filled with soil.

2- At first, columns are leached with fresh water, maintaining a permanent water level above the soil surface equal to 2 cm.

3- During the leaching process at the column bottom section, filtrate samples ($1/40^{th}$ of pore volume) were collected for the determination of chloride (Cl^-) ion concentration with the registration of time intervals.

4- The experiment is carried out on each column until the filtrate Cl^- concentration stabilizes (Which means the end of leaching).

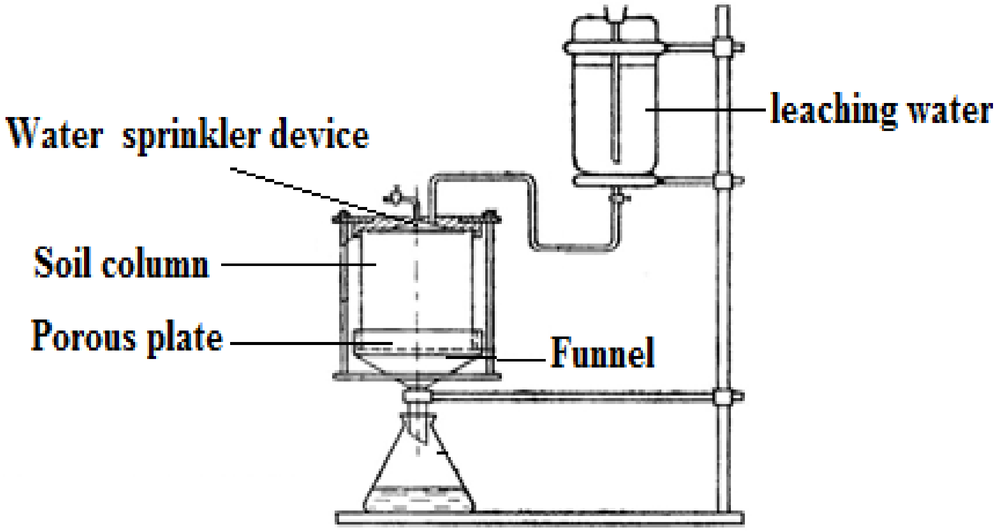

Figure 2. Schematic diagram of the experimental apparatus [7].

The representative ion in our experiment is chloride ion because it is the most harmful ion for crops and the easiest to determine. [2, 13].

Chloride concentration of each sample of the effluent is determined by the direct potentiometric method using a multiparameter HANNA HI-4522.

Soil samples were taken from a soil pit with a depth of 1 m. (corresponds to the vadose zone). Some characteristics of the soil are given in table 1. The water table at the time of sampling was 1 m below the ground surface.

Table 1: Some characteristics of soil

Horizon	0-10	10-40	40-70	70-100
Cl^- (meq/l)	1743.4	231.1	233.8	305.4
SO^{4-}(meq/l)	482.2	38.61	41.8	84.1
Ca^{2+} (meq/l)	47.81	30.83	45.9	51.9
Na+ (meq/l)	2398.7	242.5	224.7	372.2
CEC (meq/100g)	2.54	6.59	4.73	5.01
PH	8.15	7.97	8.12	8.06
θ	0.6			

3.1 Small columns

The hydrodynamic parameters of soluble salts transfer in the soil for the small columns are determined by fitting the experimental curve data to the analytical solutions of the convection-diffusion equation using STANMOD (STudio of ANalitical MODels) software developed by Van Genuchten's team of the US Salinity Laboratory. [19]

The basic solution for the equation (1)for this case and for the initial and boundary conditions cited above is: [1, 20, 23]

$$C(z,t) = 1 - \sum_{n=1}^{\infty}\left[\frac{\frac{2vL}{D} h_n \left[h_n \cos\left(\frac{h_n z}{L}\right) + \frac{vL}{2D}\sin\left(\frac{h_n z}{L}\right)\right]}{\left[h_n^2 + \left(\frac{vL}{2D}\right)^2 + \frac{vL}{D}\right]\left[h_n^2 + \left(\frac{vL}{2D}\right)^2\right]}\right] \times exp\left[\frac{vz}{2D} - \frac{v^2 t}{4DR} - \frac{h_n^2 D t}{L^2 R}\right] \ldots\ldots\ldots\ldots. (2)$$

h_n is the positive root of the equation :

$$h_n \cot(h_n) - \left(\frac{h_n^2 D^*}{vL}\right) + \left(\frac{vL}{4D}\right) = 0$$

3.2 Large columns

The determination of the coefficient $\mathbf{D^*}$ was made using the program ASC (Average Salt Concentration) developed by [15]for the simulation with the soil profile average concentration. This program solves the inverse problems for the determination of the coefficient $\mathbf{D^*}$ and the direct problems to make a prediction of soluble salts dynamics for leaching and irrigation conditions based on the solution of equation (1) (without the last term $\frac{\partial N}{\partial t}$ of crystallization)) for the initial and boundary conditions cited above [14, 15, 24]

$$\Theta(\tau,\eta) = \frac{S_\tau - C_1}{C_0 - C_1} = \sum_{n=1}^{\infty}(-1)^{n+1}\left[\frac{\sin^2(2h_n)}{2(h_n^2+\eta^2+\eta)}\right] exp\,[2\eta - (h_n^2+\eta^2)F_0] \quad \ldots\ldots (3)$$

Where: Θ is the relative concentration, C_1 is the concentration of the leaching or irrigation water [ML^{-3}], C_0 is the initial average salt concentration in soil [ML^{-3}]. S_τ is the soil solution concentration after leaching [ML^{-3}] $\eta = \frac{L}{4\lambda}$, $\lambda = \frac{D^*}{v}$, $\tau = \frac{vt}{L.R}$, $F_0 = \frac{\tau}{\eta}$, h_n is the root of the equation $\tan(2h) = \frac{2\eta h}{h^2-\eta^2}$

4. Results and discussions

4.1 Small columns

Figs. 3: a, b, c presents a fitting of the theoretical model curves of equation (1) with the experimental output curves for the 3 columns of the three horizons of 1 m of soil(0-40 cm) - (40-70 cm) (70-100 cm), respectively.

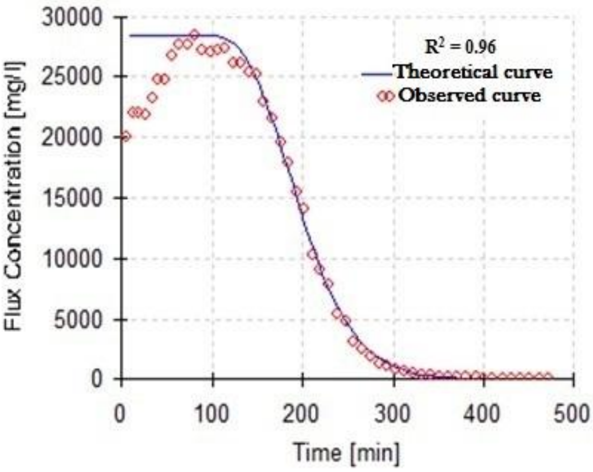

Figure 3, a. Adjustment of the experimental curve of the horizon (0-40 cm) with the analytical solutions of equation (1)

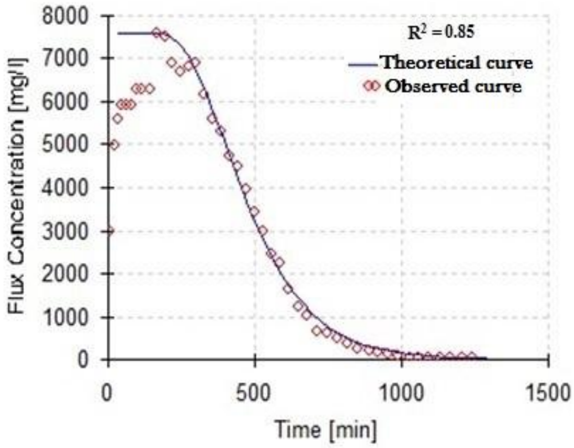

Figure 3, b. Adjustment of the experimental curve of the horizon (40-70 cm)with the analytical solutions of equation (1)

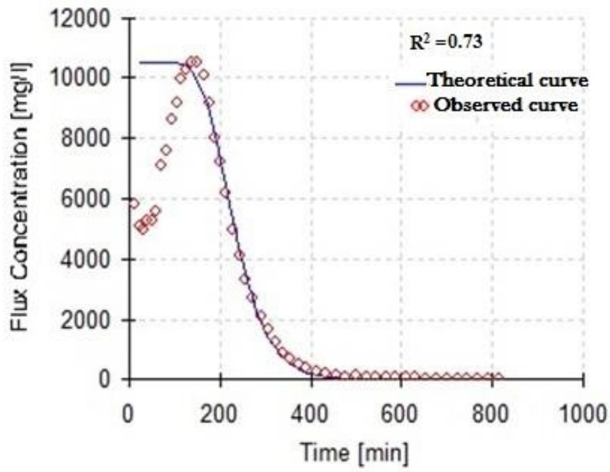

Figure 3, c. Adjustment of the experimental curve of the horizon (70-100 cm) with analytical solutions of equation (1)

The analysis of the curves shows that at the beginning of the experiment (the beginning of leaching), we observe an increase in chloride concentration followed by a decrease. This is explained by the fact of the dissolution of salt crystals in the soil solution.

As we can see, the theoretical curves were well adjusted to the observed data curves, which give us a good fit of the theoretical model with a coefficient of determination (R^2) equal to 0.96, 0.85, and 0.73, respectively. The curves also showed the validity of the model solutions of equation (1) to our soil.

4.2 Large columns

Table 2 shows the hydrodynamic parameters of soluble salts transportation in soil results (the convection - diffusion coefficient **D***, ***v,*** and **λ**) of the three tests for the large soil columns.

Table 2: Summary table of the hydrodynamic parameters results involved in mathematical modeling for the large columns

Tests	1	2	3
D*(m^2/d)	0,029	0,061	0,033
v (m/d)	0,24	0,66	0,37
λ (m)	0,12	0,092	0,089

According to [6], this difference is due to the variation in the percentage of sand particle that is to say water pore velocity variation from one horizon to another.

The analysis of the soil columns tests results shows a difference between the convection-diffusion coefficient **D***results of the large columns and the small columns. However,[14, 15, 24]demonstrated that in the case of soil salinity under leaching conditions, it is preferable to take the results that corresponding an entire soil profile (1 m) instead of the results that corresponding to a soil horizon.

5. Conclusions

The knowledge of the hydrodynamic parameters **D***,***v*** and **λ** based on the inverse mathematical model solutions for soluble salts transfer problems, allows us to make predictions of the soil hydro-saline regime, which gives the possibility of optimizing the quantities of leaching water and consequently to manage the salinization risk of irrigated lands.

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