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Geophysics

Numerical Simulation of Soil Salinity Reduction Caused by Irrigation and Introduction of Sorbent

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ABSTRACT. The soil salinity change caused by the effort of the input of external sorbent and irrigation is numerically investigated using the nonlinear non-stationary equations of filtration and kinetic equations of chemical reaction between the carbonate sodium and calcium sulfate. The numerical integration of the system of equation is realized by means of the Crank-Nicolson implicit numerical scheme for 1 month interval of time and with 1 cm and 1 min spatial and temporary steps, respectively. A method widely used in practice is thus modeled, when gypsum is introduced in the upper 20 cm layer of soil followed by irrigation.

It is shown that dissolution of sodium sulfate in water and the infiltration of the obtained solution in the soil is the main mechanism of reduction of sodium in the upper layer of the soil. The obtained liquid phase of sodium sulfate is transferred to the lower layer of soil and the increase of concentration takes place. During a month the content of the solid and liquid phases of sodium sulfate in the upper 1 m layer decreases about 2.5 times and rises 2 times at the levels $z > 1.7$ m.

The calculation shows that the use of gypsum is an additional mechanism for the reduction of the content of salt in the soil. The process of the reduction of salt by means of this procedure intensifies by 10%. The content of sodium sulfate obtained by means of the chemical reaction and infiltration increases more significantly in the upper 20 cm layer than in the lower part of the soil. At the same time, the obtained concentration of sodium sulfate is low and it cannot cause a noticeable degradation of the soil properties. In the upper 20 cm layer in 30 days calcium carbonate with volumetric content exceeds 10 times by the content of sodium sulfate. *© 2013 Bull. Georg. Natl. Acad. Sci.*

Key words: *numerical simulation, equations of filtration and kinetics, external sorbent.*

Salinization of soils is a serious problem for agriculture in Eastern Georgia. In the arid and semi-arid regions of Georgia, salted soils occupy a significant territory – about 250 thousand hectares [1]. These territories are not used or are partially used. Therefore, elaboration of soil salinity reduction methods for Georgian soils is of practical significance.

An equitable treatment of the problem of soils salinization is available from the FAO [2]. The complex computer simulation packages - SALTMOOD and PESTFADE are made to describe the movement of water and solutes in the soil system [3, 4].

In practice, salinity reduction processes are applied in several ways: (a) by leach of saline soils, (b) by application of external sorbent – calcium sulfate or other salts, (c) by using some salinity consumptive plants, and (d) by means of combining the above noted methods.

The theoretical basis for the use of practical methods of salinity reduction was elaborated in [4-10]. Attempts of such investigation for Georgian soils were made in [11, 12]. The present article continues these theoretical investigations. Here soil salinity reduction by using an external sorbent and irrigating the soil is simulated.

Formulation of the Problem

In agriculture, the gypsum drag-in process for reduction of the salinization of sodic soils is used. The corresponding chemical reaction for the humid environment of the soil may be written in the following way:

$$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4. \qquad (1)$$

After drag-in of the gypsum in a sodic soil, the sodium ion is substituted with calcium ion, and calcium carbonate and sodium sulfate is obtained (1). By means of this reaction, the content of sodium carbonate is consequently decreased and a small amount of sodium sulfate appears. In small amounts, sodium sulfate is not difficult for plants; also, it can be moved into deep layers of soil and leached from the root zone by irrigation.

These chemical and hydrological processes can be described by the following equations of diffusion and kinetic:

$$\frac{\partial W}{\partial t} + \frac{\partial WK(W + V_{Na_2CO_3} + V_{Na_2SO_4})}{\partial z} = $$
$$= \frac{\partial}{\partial z}\left[D(W + V_{Na_2CO_3} + V_{Na_2SO_4})\frac{\partial W}{\partial z}\right],$$

$$\frac{\partial V_{Na_2CO_3}}{\partial t} + \frac{\partial V_{Na_2CO_3}K(W + V_{Na_2CO_3} + V_{Na_2SO_4})}{\partial z} = $$
$$= \frac{\partial}{\partial z}\left[D(W + V_{Na_2CO_3} + V_{Na_2SO_4})\frac{\partial V_{Na_2CO_3}}{\partial z}\right] -$$
$$-S_{Na_2CO_3}(V_{Na_2CO_3} - V_{Na_2CO_3,\,sat}) - RM_{Na_2CO_3}/M_{CaSO_4},$$

$$\frac{\partial V_{Na_2SO_4}}{\partial t} + \frac{\partial V_{Na_2SO_4}K(W + V_{Na_2CO_3} + V_{Na_2SO_4})}{\partial z} = $$
$$= \frac{\partial}{\partial z}\left[D(W + V_{Na_2CO_3} + V_{Na_2SO_4})\frac{\partial V_{Na_2SO_4}}{\partial z}\right] -$$
$$-S_{Na_2SO_4}(V_{Na_2SO_4} - V_{Na_2SO_4,\,sat}) + RM_{Na_2SO_4}/M_{CaSO_4}, \quad (2)$$

$$\frac{\partial Q_{Na_2CO_3}}{\partial t} = S_{Na_2CO_3}(V_{Na_2CO_3} - V_{Na_2CO_3,\,sat}) -$$
$$-S_{Na_2SO_4}(V_{Na_2SO_4} - V_{Na_2SO_4,\,sat}),$$

$$\frac{\partial Q_{Na_2SO_4}}{\partial t} = S_{Na_2SO_4}(V_{Na_2SO_4} - V_{Na_2SO_4,\,sat}),$$

$$\frac{\partial Q_{CaCO_3}}{\partial t} = RM_{CaCO_3}/M_{CaSO_4},$$

$$\frac{\partial Q_{CaSO_4}}{\partial t} = -R, \quad R = C_{CaSO_4,Na_2CO_3} \times Q_{CaSO_4}V_{Na_2CO_3},$$

$$S_x = \begin{cases} C_xV_x(W - W_0) & \text{if} \quad V_x > V_{x,sat} \\ C_xQ_x(W - W_0) & \text{if} \quad V_x \le V_{x,sat} \end{cases},$$

where t is time; z is the vertical coordinate directed from the ground surface into the soil; x denotes the kind of chemical substance; W is the volumetric content of the soil water; $V_{Na_2CO_3}$ and $V_{Na_2SO_4}$ are the volumetric content of the liquid parts of sodium carbonate and sodium sulfate, respectively; $V_{Na_2CO_3,\,sat}$ and $V_{Na_2SO_4,\,sat}$ are the saturated volumetric content of sodium carbonate and sodium sulfate, respectively; $Q_{Na_2CO_3}$, $Q_{Na_2SO_4}$, Q_{CaCO_3}, and Q_{CaSO_4} are the volumetric content of the solid phase of sodium carbonate, sodium sulfate, calcium carbonate, and calcium sulfate, respectively; σ is the porosity of the soil; M is the volumetric content of other fractions of the solid soil; $Q_{Na_2CO_3}$ and $Q_{Na_2SO_4}$ are the velocity of dissolution of volumetric content of the corresponding soils; C_{CaSO_4,Na_2CO_3} is the time of appearance of one unit calcium carbonate; S_x is the kinematic coefficient; $M_{Na_2SO_4}$, M_{CaSO_4}, M_{CaCO_3} and $M_{Na_2CO_3}$ are the molar masses of the corresponding soils; K and D are the velocity of filtration and diffusion coeffi-

Table. Hydrological and hydrochemical parameters of soil

Depths (cm)	Porosity σ	$Q_{CaSO_4},{}_0$	$Q_{Na_2CO_3},{}_0$	Coefficient of filtration K_{max} (cm/s)	Coefficient of diffusion D_{max} (cm^2/s)
0-20	0.7	0.025	0.0025	8×10^{-5}	5×10^{-4}
20-500	0.5	0	0.0025	8×10^{-5}	5×10^{-4}

cient of the soil water and liquid part of salts [13]:

$$K(y)=K_{\max}F(y), D(y)=D_{\max}F(y),\ F=\left(\frac{y-W_0}{\sigma-W_0}\right)^{3.5},$$

where y is the volumetric content of a sum of water and dissolved parts of the substances, K_{max} and D_{max} are the maximal magnitude of the coefficients of the velocity of filtration and diffusion, respectively; W_0 is the volumetric content of the bound water.

The system (2) is solved by using the following initial and boundary conditions:

$$Q_{CaCO_3}=Q_{Na_2SO_4}=0,\ V_{Na_2CO_3}=V_{Na_2SO_4}=0,\ W=W_0,$$

$$Q_{CaSO_4}=Q_{CaSO_4},{}_0,\ Q_{Na_2CO_3}=Q_{Na_2CO_3},{}_0,\ \text{if}\ t=0,$$

$$\partial V_{Na_2CO_3}/\partial z=\partial V_{Na_2SO_4}/\partial z=0,$$

$$W(t,0)=\begin{cases}\sigma & \text{if}\ t\le 1\ \text{day}\\ W_0 & \text{if}\ t>1\ \text{day}\end{cases},\quad \text{if}\quad z=0, \qquad (3)$$

$$\partial W/\partial z=\partial V_{Na_2CO_3}/\partial z=\partial V_{Na_2SO_4}/\partial z=0,\ \text{if}\quad z=H,$$

where W_0= 0.0001. Expression of W(0, t) describes the model situation during the first day when the soil is irrigated. $Q_{Na_2CO_3},{}_0$, and $Q_{CaSO_4},{}_0$ are the known distributions of sodium carbonate and sodium sulfate into solid soil: H = 500 cm, the depth of the soil layer.

The solution of the equation system (2) with the initial and boundary conditions (3) is made using the Crankl-Nicolson implicit scheme with temporary and spatial steps equal to 6 s and 1 cm, respectively.

In the investigation, a middle dissolved sodic soil is considered. In the upper layer of soil (with 20 cm thickness) the external sorbent - gypsum, is drag-in. In Table the magnitudes of some parameters used in the model are shown.

The magnitudes of the other parameters are the following [5, 14]: $C_{Na_2CO_3}$ = 83.79×10^{-6} s^{-1}; $C_{Na_2SO_4}$ = 3.83×10^{-6} s^{-1}; $C_{CaSO_4,\,Na_2CO_3}$ = 5×10^{-6} s^{-1};

Results of calculations

Numerical simulation was made for the interval of time equal to one month of physical time. In Fig. 1, the calculated water content in the soil is shown. This figure shows that by means of action of the process of filtration and diffusion water is distributed in the soil. During the first day, when the soil is irrigated the water saturates the upper 70 cm layer of the soil. After stopping the irrigation process, the water content in the upper part of the soil decreases. Then, the water distributes into the depth of the soil and simultaneously increases the width of the water-containing layer of the soil and decreases the content of sodium carbonate in the upper 1 m layer (Figs. 2, 3).

The calculation shows that during one month the content of gypsum in the soil is decreased by about 10% (Fig. 4). Simultaneously small amounts of calcium carbonate and sodium sulfate are increased (Figs. 5, 6).

4. Discussion

Numerical simulation shows that irrigation and subsequent leaching of soil are the main procedures that can cause reduction of soil salinity in the upper part of the soil. Application of the external sorbent – gypsum promotes the intensification of this process by 10%. As a result of the above-noted two processes the salinization of soil can be decreased in the upper 2 m layer. The liquid part of sodium carbonate through infiltration from upper levels can be accumulated in the soil below 2 m and cause growth of the concentration.

The results obtained in this article have theoretical meaning. The parameters used in the model have mean

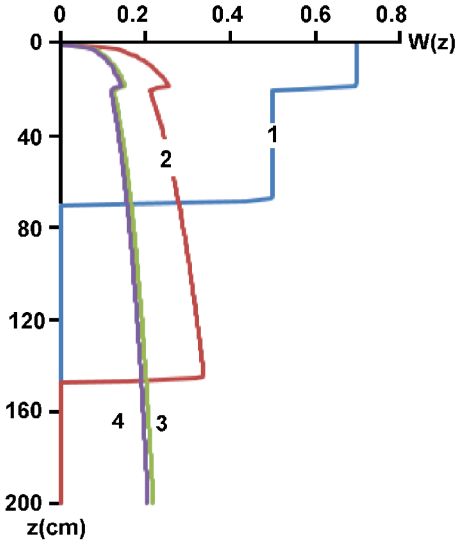

Fig. 1. The volumetric content of water in the soil obtained for t = 1, 3, 15, and 30 days – lines 1-4, respectively.

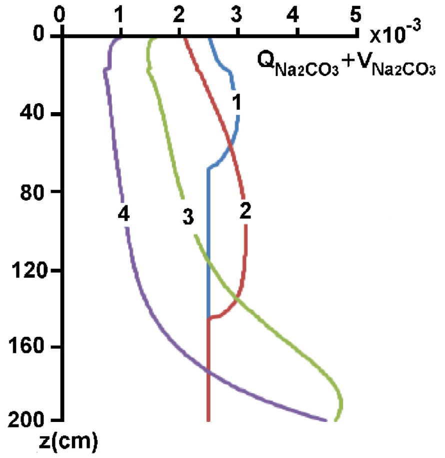

Fig. 3. The volumetric content of summary sodium carbonate in the soil for t = 1, 3, 15, and 30 days - lines 1- 4, respectively.

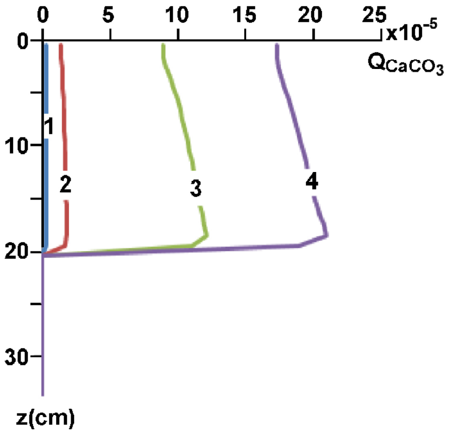

Fig. 5. The volumetric content of calcium carbonate in the soil obtained for t = 1, 3, 5, and 30 days - lines 1- 4, respectively.

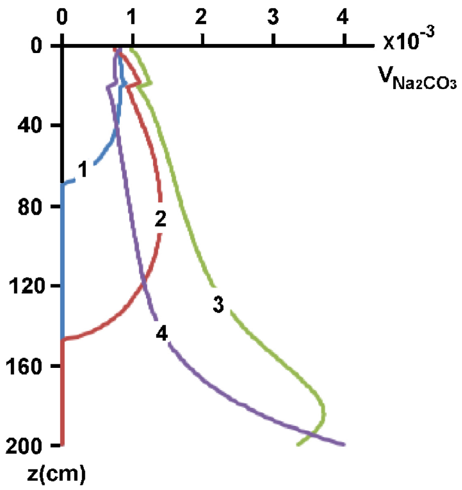

Fig. 2. The volumetric content of liquid sodium carbonate in the soil obtained for t =1, 3, 15, and 30 days – lines 1-4, respectively.

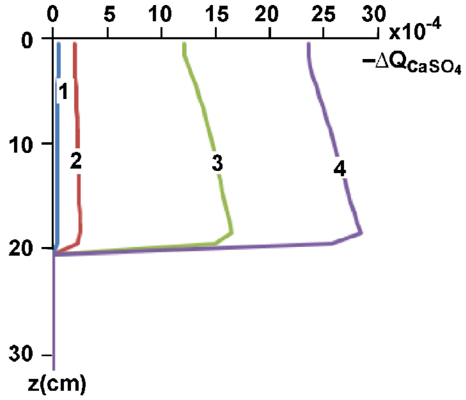

Fig. 4. The magnitude of decrease of volumetric content of gypsum in the soil for t = 1, 3, 15, and 30 days - lines 1- 4, respectively.

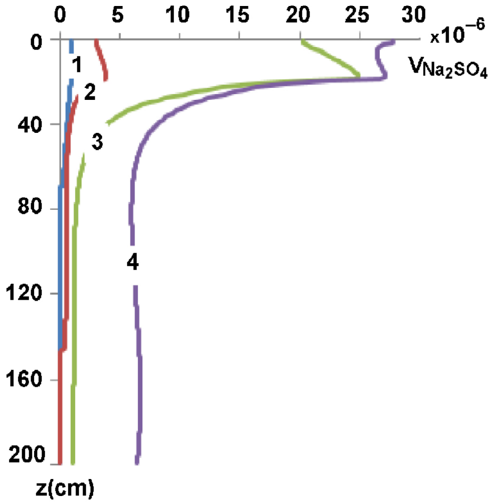

Fig. 6. The volumetric content of sodium sulfate in the soil obtained for 1 t =1, 3, 15, and 30 days - lines 1- 4, respectively.

values. For further development of the considered task, from the point of view of the possible practical application, it is necessary to continue the investigation by means of using the experimentally determined real magnitudes for the hydrological and hydrochemical parameters for soluted soils of Georgia.

გეოფიზიკა

ირიგაციით და სორბენტის შეტანით გამოწვეული ნიადაგის მარილიანობის შემცირების რიცხვითი მოდელირება

ა. სურმავა

ი. ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტის მ. ნოდიას გეოფიზიკის ინსტიტუტი, თბილისი

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სითხის ფილტრაციისა და ნატრიუმის კარბონატის კალციუმის სულფატთან ქიმიური რეაქციის კინეტიკის არაწრფივი არასტაციონალური განტოლებების გამოყენებით რიცხობრივად შესწავლილია ნიადაგში გარე სორბენტის შეტანისა და ირიგაციის შედეგად გამოწვეული ნიადაგის მარილიანობის ცვლილება. განტოლებათა სისტემის რიცხვითი ინტეგრირება განხორციელებულია კრანკ-ნიკოლსონის არაცხადი რიცხვითი სქემით 1 თვე ფიზიკური დროის ინტერვალში 1 სმ და 1 წთ სივრცითი და დროითი ბიჯებით. მოდელირებულია პრაქტიკაში ფართოდ გამოყენებული მეთოდი, როდესაც ნიადაგის ზედა 20 სმ ფენაში შეაქვთ გიფსი და შემდგომ ხდება მისი მორწყვა.

ნაჩვენებია, რომ ნატრიუმის კარბონატის წყალში გახსნა და მისი შემდგომი ინფილტრაცია ნიადაგის ქვედა ფენებში არის ნიადაგის ზედა ფენაში მარილიანობის შემცირების მთავარი მექანიზმი. ინფილტრაციის შედეგად გახსნილი ნატრიუმის კარბონატი გადაიტანება ნიადაგის სიღრმეში, სადაც ადგილი აქვს მისი კონცენტრაციის ზრდას. ერთი თვის განმავლობაში მყარი და გახსნილ ნატრიუმის კარბონატის ჯამური შემცველობა ნიადაგის ზედა 1 მ ფენაში მცირდება დაახლოებით 2.5-ჯერ და იზრდება დაახლოებით 2-ჯერ > 1.7 მ დონეებზე.

გამოთვლებმა აჩვენა, რომ სორბენტის გამოყენება არის მარილიანობის შემცირების დამატებითი მექანიზმი. მისი საშუალებით ხდება პროცესის ინტენსიფიკაცია 10%-ით. ქიმიური რეაქციის შედეგად წარმოშობილი ნატრიუმის სულფატის შემცველობა პროცესის არაწრფივობის გამო ნიადაგის 20 სმ ფენაში იზრდება უფრო სწრაფად, ვიდრე ქვედა ფენაში. ამასთან, მთლიანად ნატრიუმის სულფატის შემცველობა მეტად მცირეა და მას არ შეუძლია გამოიწვიოს ნიადაგის თვისების შესამჩნევი გაუარესება. ნიადაგის ზედა 20 სმ ფენაში წარმოიშობა კალციუმის კარბონატი, რომლის მოცულობითი შემცველობა 30 დღის განმავლობაში დაახლოებით 10-ჯერ აღემატება ნატრიუმის სულფატის მოცულობით შემცველობას.

მიღებული შედეგები თვისებრივად სწორად ასახავს მარილიანობის შემცირების პროცესს. იმისათვის რომ შესაძლებელი გახდეს რიცხვითი მოდელის სიზუსტის რაოდენობრივი შეფასება, საჭიროა ექსპერიმენტული გაზომვებით განისაზღვროს ჰიდროქიმიური პარამეტრების დაზუსტებული მნიშვნელობები და ისინი გამოყენებული იქნას რიცხვითი მოდელირებისას.

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