Journal of the Georgian Geophysical Society,
Issue B, Physics of Atmosphere, Ocean, and Space Plasma, v.15, 2011-2012, pp. 46-51

A numerical simulation of the soil salinity reduction

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Abstract

Using the filtration and kinetic equations of the chemical reaction between the carbonate sodium and calcium sulfate, the soil salinity change is numerically simulated. It is shown that an application of external sorbent intensifies reduction of sodium in the upper 20 cm layer of the soil on 10%. The process of infiltration causes a displacement of liquid phase of sodium carbonate in the lower depths (z > 2 m) from the upper levels and rise its concentration in the lower levels.

1. Introduction

Salinization of the soils is a serious problem for agriculture of the East Georgia. In the arid and semi-arid regions of Georgia, the salted soils occupied a significant territory – about 250 thousand hectare [1].These territories aren't used or are small used in agriculture of the republic. Therefore, an elaboration of the soil salinity reduction method for the Georgian soils has a practical importance.

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

In the practice, the salinity reduction processes are doing by several ways (a) by leach of the saline soils, (b) by application of a external sorbent – calcium sulfate or others salts, (c) by using the some solinity consumptive plants (xerophyte, arid glasswort, and etc.), and (d) by means of combining of the noted above methods.

The theoretical basis for use of the practical methods was elaborated in [4- 11]. A tries of such investigation for the Georgian soils were made in [12, 13]. In the presented article, these theoretical investigations are continued. Here is simulated the soil salinity reduction by action of the external sorbent and following it a watering of the soil.

2. Formulation of the Problem

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

$$CaSO_4 + Na_2CO_3 \longrightarrow CaCO_3 + Na_2SO_4 \quad (1)$$

After drag-in of the gypsum in the sodic soil, the sodium ion is substituting with calcium ion, and it is obtained the calcium carbonate and sodium sulfate. By means of this reaction, the sodium carbonate is reduced and the small amount of sodium sulfate appears. In small amounts, the sodium sulfate aren't difficult for plants and it can be moved in deep layers of soil and leached from the root zone by irrigation water.

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

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

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

$$-S_{Na_2CO_3}(V_{Na_2CO_3}-V_{Na_2CO_{3,sat}})-RM_{Na_2CO_3}/M_{Ca\mathrm{SO}_4},$$

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

$$-S_{Na_2SO_4}(V_{Na_2SO_4}-V_{Na_2SO_{4,sat}})+RM_{Na_2SO_4}/M_{Ca\mathrm{SO}_4},$$

(2)

$$\frac{\partial Q_{Na_2CO_3}}{\partial t}=S_{Na_2CO_3}(V_{Na_2CO_3}-V_{Na_2CO_{3,sat}})-S_{Na_2SO_4}(V_{Na_2SO_4}-V_{Na_2SO_{4,sat}}),$$

$$\frac{\partial Q_{CaCO_3}}{\partial t}=RM_{CaCO_3}/M_{Ca\mathrm{SO}_4},\quad \frac{\partial Q_{Na_2SO_4}}{\partial t}=S_{Na_2SO_4}(V_{Na_2SO_4}-V_{Na_2SO_{4,sat}}),$$

$$\frac{\partial Q_{CaSO_4}}{\partial t}=-R,\quad R=C_{CaSO_4,Na_2CO_3}\times Q_{Ca\mathrm{SO}_4}V_{Na_2CO_3},$$

$$\sigma=1-M-Q_{CaSO_4}-Q_{Na_2CO_3}-\mathrm{Q}_{CaCO_3}-Q_{Na_2\mathrm{SO}_4},$$

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

where t is the time; z is the vertical coordinate directed from the ground surface into soil; x denotes the 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 soluted parts of sodium carbonate and sodium sulfate, respectively; $\mathrm{V}_{\mathrm{Na}_2\mathrm{CO}_3,sat}$ და $V_{Na_2SO_4,sat}$ are the saturated volumetric content of sodium carbonate and sodium sulfate, respectively; $Q_{Na_2CO_3}$, $Q_{Na_2SO_4}$, $Q_{Ca_2CO_3}$, and $Q_{Ca_2SO_4}$ 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 another fractions of the solid soil; $C_{Na_2\mathrm{CO}_3}$ and $C_{Na_2\mathrm{SO}_4}$ are the velocity of dissolution of volumetric content of the correspondent soils; $C_{CaSO_4,\,Na_2CO_3}$ is the time of an appearance of one unit calcium carbonate the chemical reaction; S_x is the kinematic coefficient; $M_{Na_2SO_4}$, $M_{Ca\mathrm{SO}_4}$, $M_{Ca\ CO_3}$, and $M_{Na_2CO_3}$ are the molar masses of the correspondent soils; K and D are the velocity of filtration and diffusion coefficient of the soil water and soluted soils [14]:

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

where y is the volumetric content of a sum of water and soluted 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 soluted by using the following initial and boundary conditions:

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

$$Q_{Na_2CO_3} = Q_{Na_2CO_3,0}\ ,\quad Q_{Ca_2SO_4} = Q_{Ca_2SO_4,0}\ , \qquad \text{if} \quad t = 0,$$

$$W(t,0) = \begin{cases} \sigma & \text{if } t \le 1 \text{ day} \\ W_0 & \text{if } t > 1 \text{ day} \end{cases}\ ,\quad \partial V_{Na_2CO_3}/\partial z = \partial V_{Na_2SO_4}/\partial z = 0, \qquad \text{if} \quad z = H, \quad (3)$$

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

where $W_0 = 0.0001$. Expression of W(0, t) describes the model situation when during one first day the soil is irrigated. After of this interval of time, the soil surface becomes dry. $Q_{Na_2CO_3,0}$ and $Q_{Ca_2SO_4,0}$ are the known distributions of sodium carbonate and sodium sulfate into solid soil: H = 500 cm is the depth of the soil.

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

It is considered a middle soluted sodic soil. In the upper layer of soil (with 20 cm thicknes), the external sorbent the gypsum is drag-in. In Table 1, the magnitudes of some parameters used in the model are shown.

Table 1. The hydrological and hydrochemical parameters of soil

depths (cm)	poros-ity σ	$Q_{Ca_2SO_4,0}$	$Q_{Na_2CO_3,0}$	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};

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

3. Results of calculations

The numerical simmulation was made for the interval of time equal to one month of physical time. In the Fig. 1, the calculated water cotent in the soil is shown. This figure shows that by means of action of the process of filtration and diffusion the 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 of 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 soil.

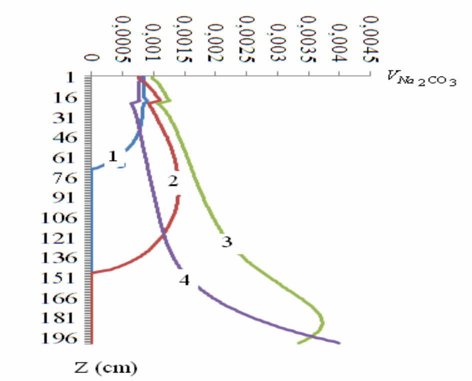

Fig. 1. The volumetric contet of water in the soil obtained for t = 1, 3, 15, and 30 day – lines 1-4, respectively.

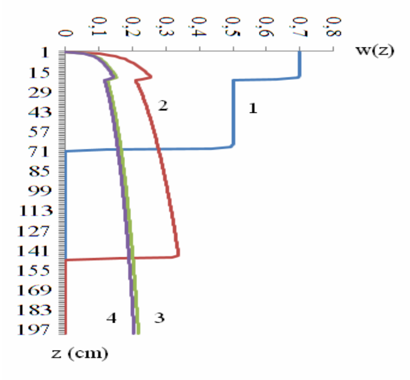

Fig. 2. The volumetric content of liquid sodium carbonate in the soil obtained for t = 1, 3, 15, and 30 days – lines 1-4, respectively.

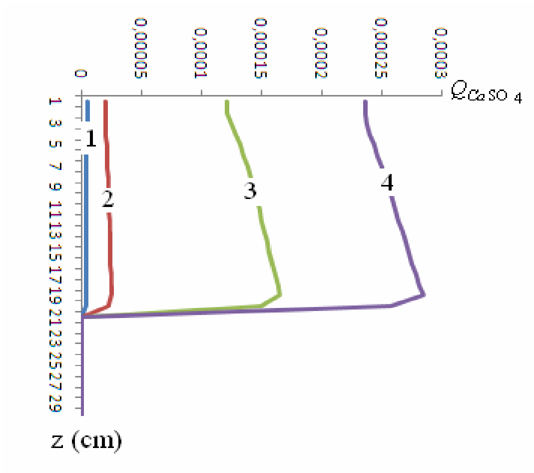

Fig. 3. The volumetric contet of summary sodium carbonate in the soil for t = 1, 3, 15, and 30 days – lines 1- 4, respectively.

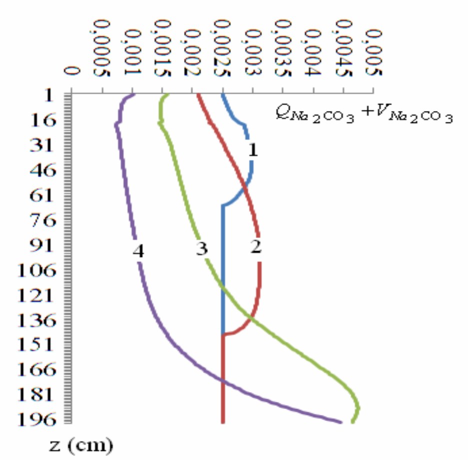

Fig. 4. The magnitude of decrease of volumetric content of gypsum in the soil for t = 1, 3, 15, and 30 days – lines 1- 4, respectively.

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

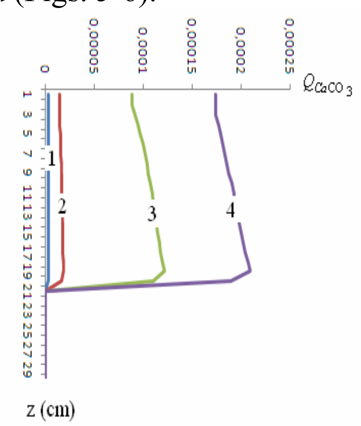

Fig. 5. The volumetric content of calcium carbonate in the soil obtained for t = 1, 3, 15, and 30 days – lines 1- 4, respectively.

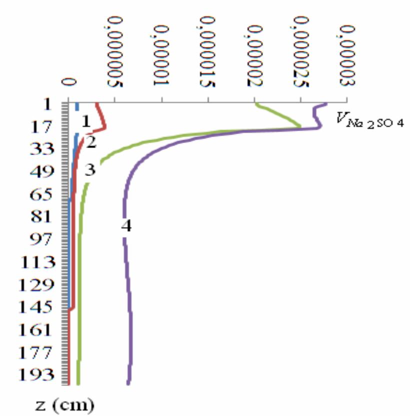

Fig. 6. The volumetric content of sodim sulfate in the soil obtained for t =1, 3, 15, and 30 days – lines 1- 4, respectively.

4. Discussion

The numerical simulation shows that the irrigation and followed it leaching of soil are the main procedures that can cause reduction of soil salinity in the upper part of siol. An application of the external sorbent – gypsum promotes to intensify this process by 10% . In the issue of action of noted above two processes the salinization of soil can be decreased in the upper 2 m layer. The liquid part of sodium carbonate through infiltration dissolved salt from upper levels can be accumulated in soil below 2 m and cause a grow their concentration.

The results obtained in this article have quantitative meaning, because we couldn't find the real measured magnitudes for kinematic parameters of processes of dissolution and chemical reaction. Parameters, used in the article, were taken from some handbooks and they can be used only as approximately values for soil of Georgia. Therefore, for further development of the theoretical investigation of considered task it is nessesury to determine experimentally the real magnitudes of the kinematic, filtration and hydrochemical parameters for salinited soils of Georgia.

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(Received in final form 20 December 2012)

Численное моделирование уменьшения солёности почвы

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Резюме

С помощью уравнения фильтрации и уравнения кинетики для химической реакции карбоната натрия с сульфатом кальция численно смоделировано изменение солёности почвы. Показано, что внесение сорбента интенсифицирует уменьшение натрия в 20см слое почвы на 10%. Процесс инфильтрации вызывает перемещение жидкой фазы сульфата натрия из верхних уровней в нижние уровни *(z > 2 м)* и рост его содержания на нижных уровнях почвы.

ნიადაგის მარილიანობის შემცირების რიცხვითი მოდელირება

ა. ა. სურმავა

რეზიუმე

სითხის ფილტრაციისა და ნატრიუმის კარბონატის კალციუმის სულფატთან ქიმიური რეაქციის კინეტიკის განტოლების გამოყენებით რიცხობრივად მოდელირებულია ნიადაგის მარილიანობის ცვლილება. ნაჩვენებია, რომ სორბენტის შეტანა იწვევს განმარილიანების პროცესის ინტენსიფიცირებას დაახლოებით 10%-ით ნიადაგის ზედა 20 სმ ფენაში. ინფილტრაცია იწვევს გახსნილი ნატრიუმის სულფატის გადატანას ნიადაგის ზედა ნაწილიდან ქვედაში და ქვედა ფენაში (z > 2 მ) მისი კონცენტრაციის ზრდას.