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Exchange of salt and moisture in the underground water management

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Exchange of salt and moisture in the underground water management

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Abstract. Water – as moisture, has an essential role in all biochemical processes of plants, all vital processes, occurring in a vegetative organism, can proceed normally only under the condition of sufficient saturation of cages by moisture. Results of theoretical researches on dynamics of ground humidity have shown: (1) similarity of physical processes of change of humidity of soil on different irrigated areas. (2) hysteresis of the nature of humidity at irrigation and drainage. (3) the sharp recession of humidity of soil in the root zone. The developed models (33) - (34) can be used in the calculation of moisture and salt transfer both in the initial period of plant development and in the calculation of washing of saline lands. The use of models and the coefficients of the mathematical model to determine the parameters of moisture and salt transfer make it possible to calculate the reserve of soil moisture and optimize the sowing time at its maximum value.

1. Introduction

Among the main factors in the arid zone, an important role is played by the water and thermal regimes of soils, which mainly determine the fate of the crop of irrigated crops. This is explained by the fact that the subsoil processes are closely related to weather conditions and, depending on their behavior, the need for appropriate ameliorative impacts on the agricultural field is established.

Regional water resource limitation is requiring the development of more accurate and mathematically sound methods for managing moisture in the irrigated field. Such work was carried out in major scientists schools: F.B. Abutaliev [1, 2], S.F. Averyanov [3], V.R. Volobuev [4], V.K. Konstantinov [5], F.A. Baraev [6], Khudaykulov S.I. [7], B.M. Shumakov [8], and others.

S.F. Averyanov [3] emphasizes that the similarity of physical processes: “Just as the heat content depends on temperature, the volumetric moisture of the soil θ depends on the gradient of the potential of water F. Like the heat flux depends on the temperature gradient, the speed of water in soil depends on the gradient of potential”.

In the Acad. F.B.Abutaliev works [1, 2] change in humidity in the presence of root, arable and subsurface layers are presented in the form:

$$
\begin{cases}
\dfrac{d}{dz}\left[D_1(W_1)\dfrac{dW_1}{dz}\right]-\dfrac{dK_1}{dz}-\dfrac{12E_T}{7(\delta+u_*)}\left[1-\dfrac{z}{2(\delta+u_*)}-\dfrac{z^2}{2(\delta+u_*)^2}\right]=\dfrac{dW_1}{dt}, & (0\le z\le\delta+u_*)\\
\dfrac{d}{dz}\left[D_1^*(W_1^*)\dfrac{dW_1^*}{dz}\right]-\dfrac{dK_1^*}{dz}=\dfrac{dW_1^*}{dt}, & (\delta+u_*\le z\le z_1)\\
\dfrac{d}{dz}\left[D_2(W_2)\dfrac{dW_2}{dz}\right]-\dfrac{dK_2}{dz}=\dfrac{dW_2}{dt}, & (z_1\le z\le L)
\end{cases}
$$

V.R. Volobuev [4] notes that the osmotic potential, which plays an important role in maintaining the plant tissue turgor, is negative. With the complete plant cell turgor, the full potential of water in plant cells is close to zero, since the osmotic and matrix potentials at different signs have the same value.

V.K. Konstantinov's researches [5] confirmed the hypothesis that young roots absorb water more than old ones, due to the large number of small root hairs providing a large surface area for water absorption.

According to Baraev F.A. [6] and Khudaykulov S.I. [7] the moisture wilting point or the lower limit of moisture available for plants is the soil moisture at which the plants wilt and do not restore turgor after being placed in a humid atmosphere for one night.

B.M.Shumakov [8] and R.A. Muradov [9-16] give a model of the rate of soil desiccation by plant roots. Considering the roots of plants as a system of cylindrical capillaries with permeable walls, they identified a portion of a root of unit length surrounded by a cylindrical feeding zone.

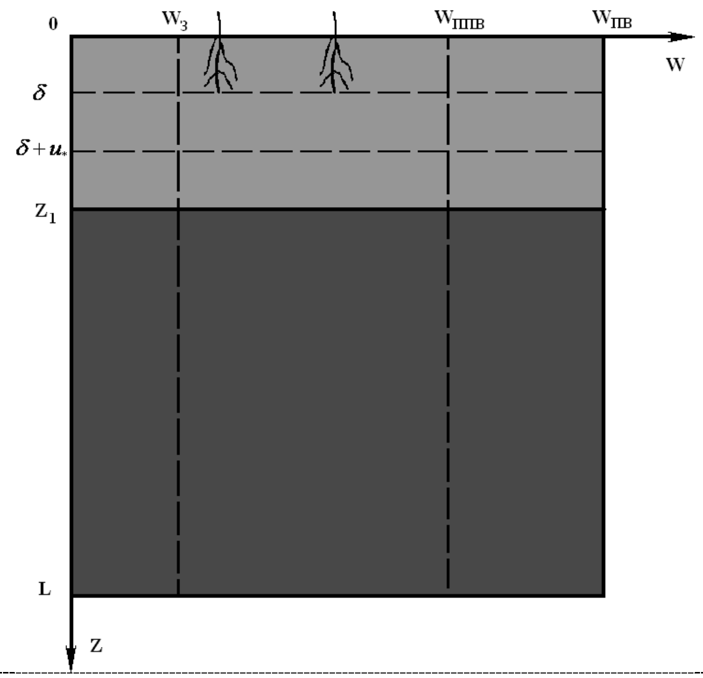

Figure 1. Schematic section of soil $0 \le Z \le Z_1$ – arable layer; $Z_1 \le Z \le L$ - subsoil layer Introduction

At this stage, it is necessary, with the aim of reclamation, to use mathematical models for soils most common in the region. Such models are important as a basis for optimizing the use of land resources in irrigated areas by changing the structure of land use, specializing in agriculture, etc. With these studies, it is necessary to use the achievements of the fundamental sciences, the mathematical apparatus, and the computer. The introduction of new methods in land reclamation is a slow and time-consuming process, since soils must be considered as a multiparameter and dynamically changing object [1, 2, 3].

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The conducted studies to date have proved the inconsistency of the interpretations of the management of the productivity of agroecosystems, when only a few isolated indicators were taken into account or the informativeness of the integral indicators was usually judged from the data of correlation and regression analyzes that do not always reflect the actual processes taking place in the soil- plant". In the methodology for assessing soils as an object of intensive agricultural use, a new stage has come-the transition from bathing assessments, studies of individual optimal parameters to the analysis of the productivity of agroecosystems based on their mathematical modeling [4;5].

2. Methods

The spatial-temporal dynamics of soil moisture were investigated in several Water Consumers Association in Uzbekistan.

On the demonstration site, cotton was grown; space between the rows was 90 cm. Five sampling sites (four under cotton grown area and one at non-vegetated area – control) with four replications of each were selected randomly. Soil samples were collected annually during 2016-2017.

The experiment consists of two parts: The first is the analysis of the dynamics of soil moisture based on the irrigation frequency. The soil moisture was measured right before and after the irrigation, the next was as well as 1, 2, 3, and 5 days before and after the irrigation. The sampling was replicated four times. Moisture is determined from 10-cm layers and in the root and topsoil - from 0.5 and 5-10 cm layers. The sampling arrangement is shown in Figure 2.

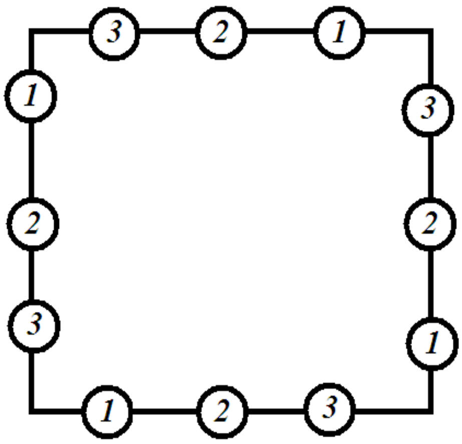

Figure 2. Sampling arrangement with fourfold replication of moisture determination

Moisture (M) was calculated to determine the profile of the volumetric water content (Vs) of soil. Both M and the soil water deficit amount (DWC) are defined by

$$M = Vs \cdot H \cdot 10 \quad (1)$$

$$DWC = SFC - WC \quad (2)$$

where *Vs* is the volumetric water content (mm), *H* is the depth of soil (cm), and SFC is the soil field capacity (mm).

SFC was measured by the indoor J. C. WILCOX method. The bulk density of the soil layer was measured by the cutting ring method and repeated three times. All climatic data, such as rainfall and evaporation were provided by a weather station near the field.

In the initial period of plant development under steady-state conditions, when transpiration of Em can be neglected, the following mathematical model will be used for a two-layer medium consisting of arable and subarable layers [6, 7, 8].

With soluble salts and small content in the solid phase (for example, chlorine), the equation of salt transfer satisfactorily describes the distribution of salts observed in nature and experiments without the last term $\gamma(c_s - c)$, i.e.

3. Results and Discussion

We note that in this case D takes into account the peculiarities of the motion of solutions in a nonsolvent medium (the so-called longitudinal and transverse effects) and is not equal to the usual diffusion coefficient in a resting solution.

$$\begin{cases} 0 \le z \le z_1 \\ \frac{d}{dz}\left[D_1(W_1)\frac{dW_1}{dz}\right] - \frac{dK_1(W_1)}{dz} = 0, \\ \frac{d}{dz}\left[D_{N_1}(W_1)\frac{dN_1(W_1)}{dz}\right] - \frac{dV_{N_1}(W_1)}{dz} = 0, \\ z_1 \le z \le L \\ \frac{d}{dz}\left[D_2(W_2)\frac{dW_2}{dz}\right] - \frac{dK_2(W_2)}{dz} = 0, \\ \frac{d}{dz}\left[D_{N_2}(W_2)\frac{dN_2(W_2)}{dz}\right] - \frac{dV_{N_2}(W_2)}{dz} = 0 \end{cases} \tag{3}$$

$$W_1(0) = W_{PR} = const, \tag{4}$$

$$N_1(0) = N_{PR} = const \tag{5}$$

$$W_1(Z_1) = W_2(Z_1) \tag{6}$$

$$N_1(Z_1) = N_2(Z_1) \tag{7}$$

$$\left[K_1(W_1) - D_1(W_1)\frac{dW_1}{dz}\right]_{Z=Z_1} = \left[K_2(W_2) - D_2(W_2)\frac{dW_2}{dz}\right]_{Z=Z_1} \tag{8}$$

$$V_{N_1}(W_1) - D_{N_1}(W_1)\frac{dN_1(W_1)}{dz}\bigg|_{Z=Z_1} = V_{N_2}(W_2) - D_{N_2}(W_2)\frac{dN_2(W_2)}{dz}\bigg|_{Z=Z_1} \tag{9}$$

$$W_2(L) = W_{MC} \tag{10}$$

$$N_2(L) = N_{MC} \tag{11}$$

where: the following designations are entered for the arable and sub-plow layers respectively: W_1, W_2 are the volumetric humidities; coefficients of moisture conductivity are adopted in the form [9, 10, 11]:

$$K_1(W_1) = A_1 e^{A_2 z}, K_2(W_2) = B_1 e^{B_2 z} \tag{12}$$

the speed of water movement in the ground is taken as [12,13]:

$$V_{N_1} = R_1 e^{R_2 Z}, \quad V_{N_2} = P_1 e^{P_2 Z} \tag{13}$$

Since the stationary regime is considered for the diffusivity coefficients, their mean values

$$D_1(W_1) = D_1 = const, \quad D_2(W_2) = D_2 = const \tag{14}$$

$$D_{N_1}(W_1) = D_{N_1} = const, \qquad D_{N_2}(W_2) = D_{N_2} = const, \tag{15}$$

where: L is the groundwater depth, m;

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Z_1 is the boundary between arable and subsoil layers, m;

W_{PR} is some intermediate moisture capacity between wilting moisture W_3 and the maximum moisture capacity W_{ppv}, i.e.

$$W_3 \prec W_{PR} \prec W_{PPV} \tag{16}$$

where: W_{MS} is the full moisture capacity;

Z is the vertical coordinate directed down from the earth's surface.

Also N_{PR} it is an intermediate concentration of the salts between the concentration of the salts in the wash water N_W and the concentration of the limiting saturation of water N_S, i.e.

$$N_W \le N_{PR} \le N_S \tag{17}$$

As a result of these notations, we rewrite the boundary value problem (1) - (9) as follows

$$\begin{cases} D_1 \dfrac{d^2W_1}{dz^2} - A_1A_2e^{A_2Z} = 0 \\ D_{N_1} \dfrac{d^2N_1}{dz^2} - R_1R_2e^{R_2Z} = 0 \\ D_2 \dfrac{d^2W_2}{dz^2} - B_1B_2e^{B_2Z} = 0 \\ D_{N_2} \dfrac{d^2N_2}{dz^2} - P_1P_2e^{P_2Z} = 0 \end{cases} \tag{18}$$

$$A_1e^{A_2Z} - D_1 \frac{dW_1}{dz}\bigg|_{Z=Z_1} = B_1e^{B_2Z} - D_2 \frac{dW_2}{dz}\bigg|_{Z=Z_1} \tag{19}$$

$$R_1e^{R_2Z} - D_{N_1} \frac{dN_1}{dz}\bigg|_{Z=Z_1} = P_1e^{P_2Z} - D_{N_2} \frac{dN_2}{dz}\bigg|_{Z=Z_1} \tag{20}$$

where $A_1, A_2, B_1, B_2, D_1, D_2, R_1, R_2, P_1, P_2, D_{N1}, D_{N2}$ are some constants determined by comparing the analytical solution with the experimental data [14];

Integrating the first equation of system (16) we will successively find

$$\frac{d^2W_1}{dz^2} - \frac{A_1A_2}{D_1}e^{A_2Z} = 0$$

$$W_1 = \frac{A_1}{A_2D_1}e^{A_2Z} + C_1z + C_2 \tag{21}$$

Similarly, after integrating the other equations of the same system, we obtain

$$N_1 = \frac{R_1}{R_2D_{N_1}}e^{R_2Z} + C_3z + C_4 \tag{22}$$

$$W_2 = \frac{B_1}{B_2D_2}e^{B_2Z} + C_5z + C_6 \tag{23}$$

$$N_2 = \frac{P_1}{P_2D_{N_2}}e^{P_2Z} + C_7z + C_8 \tag{24}$$

Using condition (2), we find from (19)

$$C_2 = W_{PR} - \frac{A_1}{A_2D_1} \tag{25}$$

We also determine C_4 from the conditions (3) and (26)

$$C_4 = N_{PR} - \frac{R_1}{R_2D_{N1}} \tag{26}$$

On the basis of (6) and (7) we find the relation

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$$C_5 = C_1 \frac{D_2}{D_1} \tag{27}$$

$$C_7 = C_3 \frac{D_{N_2}}{D_{N_1}} \tag{28}$$

Expressions (8) and (9), using (8) and (9), we obtain

$$W_{PV} = \frac{B_1}{B_2 D_2} e^{B_2 L} + C_5 L + C_6 \tag{29}$$

$$N_{PV} = \frac{P_1}{P_2 D_{N_2}} e^{P_2 L} + C_3 \frac{D_{N_2}}{D_{N_1}} L + C_8 \tag{30}$$

The dependence of C_6 on C_l is found from (24) with allowance for (22)

$$C_6 = W_{PV} - \frac{B_1}{B_2 D_2} e^{B_2 L} - C_1 \frac{D_2}{D_1} L \tag{31}$$

The value of C8 is determined from (19) with allowance for (23)

$$C_8 = N_{PV} - \frac{P_1}{P_2 D_{N_2}} e^{P_2 L} - C_3 \frac{D_{N_2}}{D_{N_1}} L \tag{32}$$

Relation (4) with allowance for (21), (22) and (26) allows us to determine C_l from equality

$$W_{PV} - \frac{B_1}{B_2 D_2}\left[e^{B_2 L} - e^{B_2 Z_1}\right] - C_1 \frac{D_2}{D_1}\left[L - Z_1\right] = W_{PV} - \frac{A_1}{A_2 D_1}\left[e^{A_2 Z_1} - 1\right] + C_1 Z_1$$

From where we find

$$C_1 = \frac{W_{PV} - W_{PR} - \frac{A_1}{A_2 D_1}\left[e^{A_2 Z_1} - 1\right] - \frac{B_1}{B_2 D_2}\left[e^{B_2 L} - e^{B_2 Z_1}\right]}{\frac{D_2}{D_1}\left[L - Z_1\right] + Z_1} \tag{33}$$

It is possible to establish the value of C_3 from equation (22), (23), and (27)

$$N_{PV} - \frac{P_1}{P_2 D_{N_2}}\left[e^{P_2 L} - e^{P_2 Z_1}\right] - C_3 \frac{D_{N_2}}{D_{N_1}}\left[L - Z_1\right] = N_{PR} - \frac{R_1}{R_2 D_{N_1}}\left[e^{R_2 Z_1} - 1\right] + C_3 Z_1$$

Hence we find

$$C_3 = \frac{N_{PV} - N_{PR} - \frac{R_1}{R_2 D_{N_1}}\left[e^{R_2 Z_1} - 1\right] - \frac{P_1}{P_2 D_{N_2}}\left[e^{P_2 L} - e^{P_2 Z_1}\right]}{\frac{D_{N_2}}{D_{N_1}}\left[L - Z_1\right] + Z_1} \tag{34}$$

Substituting the values of arbitrary C_1, C_2, C_3 and C_4 in (19) and (20) we obtain the distribution of volumetric moisture and salt concentration in the arable layer as a function of z [15;16;17].

$$W_1 = W_{PR} + \frac{A_1}{A_2 D_1}\left[e^{A_2 Z} - 1\right] + \left[\frac{W_{PV} - W_{PR} - \frac{A_1}{A_2 D_1}\left[e^{A_2 Z_1} - 1\right] - \frac{B_1}{B_2 D_2}\left[e^{B_2 L} - e^{B_2 Z_1}\right]}{\frac{D_2}{D_1}\left[L - Z_1\right] + Z_1}\right] z \tag{35}$$

$$N_1 = N_{PR} + \frac{R_1}{R_2 D_{N_1}}\left[e^{R_2 Z} - 1\right] + \left[\frac{N_{PV} - N_{PR} - \frac{R_1}{R_2 D_{N_1}}\left[e^{R_2 Z_1} - 1\right] - \frac{P_1}{P_2 D_{N_2}}\left[e^{P_2 L} - e^{P_2 Z_1}\right]}{\frac{D_{N_2}}{D_{N_1}}\left[L - Z_1\right] + Z_1}\right] z \tag{36}$$

$0 \le z \le Z1$

The definite values of the constants C_5 C_6, C_7, and C_8 in (21) and (22) yield the distribution of the volumetric moisture content and the salt concentration in the subpolar layer as a function of z.

$$W_2 = W_{PV} - \frac{B_1}{B_2 D_2}\left(e^{B_2 L} - e^{B_2 Z}\right) - \left(\frac{W_{PV} - W_{PR} - \frac{A_1}{A_2 D_1}\left[e^{A_2 Z_1} - 1\right] - \frac{B_1}{B_2 D_2}\left[e^{B_2 L} - e^{B_2 Z_1}\right]}{\left[L - Z_1\right] + Z_1} \right)(L - z) \quad (37)$$

$$N_2 = N_{PV} - \frac{P_1}{P_2 D_{N_2}}\left(e^{P_2 L} - e^{P_2 Z}\right) - \left(\frac{N_{PV} - N_{PR} - \frac{R_1}{R_2 D_{N_1}}\left[e^{R_2 Z_1} - 1\right] - \frac{P_1}{P_2 D_{N_2}}\left[e^{P_2 L} - e^{P_2 Z_1}\right]}{\left[L - Z_1\right] + Z_1} \right)(L - z) \quad (38)$$

$Z1 \leq z \leq L$

The change in moisture content and concentration of salts at various initial surface moisture indices without taking into account the development of the plant root system for the conditions of the WUA "Norcheyev" in the Khavast region of the Syrdarya region is shown in Figure 2. The determination of the constants was carried out according to the acad. F.B. Abutaliev given in [18, 19]

Table 1. Coefficients of the mathematical model for determining the parameters of moisture and salt transfer

Location of the object	Khavast district						
Farms	«Baland toglar»	Baraka	Akhmad Khojayev	Chinor	Khavast simosi	Dariyev Ibodullo	Kushkecik
Mechanical composition	Heavy loam			Medium loam		Light loam	
$A_1 \times 10^{-4}$	4.84	2.18	2.02	5.37	2.30	35.71	32.58
A_2	2.01	1.74	1.57	2.23	2.39	2.30	2.20
$B_1 \times 10^{-4}$	4.55	3.41	1.67	2.26	1.53	50.71	36.40
B_2	2.30	2.51	2.43	2.42	2.64	1.83	2.09
$D_1 \times 10^{-3}$	3.67	4.35	5.14	6.75	5.43	3.94	3.08
$D_2 \times 10^{-3}$	9.71	1.71	2.29	12.19	18.76	6.74	7.70
$R_1 \times 10^{-4}$	34.22	31.21	32.69	3.23	3.60	5.04	3.70
R_2	2.17	2.07	2.12	2.06	1.88	2.18	1.90
$P_1 \times 10^{-4}$	48.60	34.87	41.45	1.82	2.97	6.29	1.97
P_2	1.72	1.96	1.84	2.50	2.42	2.38	2.43
$D_{N1} 10^{-3}$	3.74	2.91	3.31	5.77	4.98	2.88	5.94
$D_{N2} 10^{-3}$	6.43	7.35	6.88	11.08	6.48	9.12	7.24

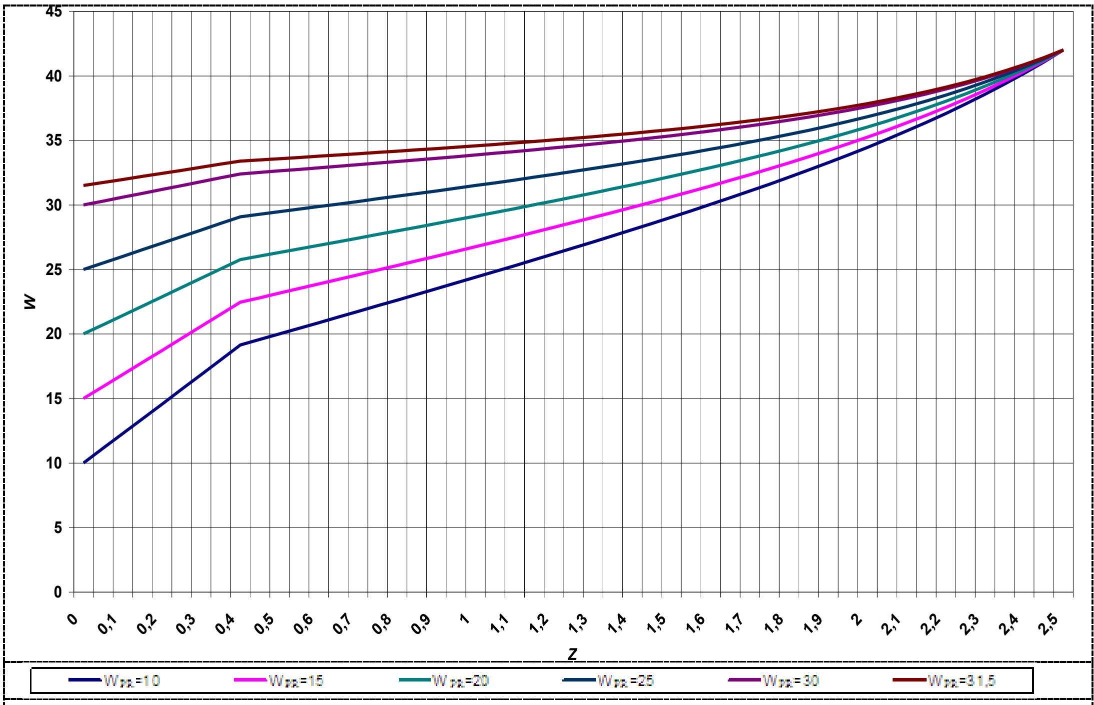

Figure 3. Distribution of humidity

Figure 3 shows the change in soil moisture during the initial period of plant development (winter wheat). The bend point on the graph indicates the boundary between the arable and sub-plow layers (42 sm) [20].

This problem-solution along with the computer models use allows to establish the quantitative characteristics of moisture and salt and to reveal their dynamics in the system "soil - water - plant". On the other hand, this makes it possible for a simple farmer, householders, as well as WCA employees and other water management organizations to forecast, based on different “scenarios,” moisture and salt changes, as well as to plan various (agro-technical, reclamation, etc.) measures

4. Conclusions

1. The developed models (33) - (34) can be used in the calculation of moisture and salt transfer both in the initial period of plant development and in the calculation of washing of saline lands.

2. The use of models and the coefficients of the mathematical model to determine the parameters of moisture and salt transfer make it possible to calculate the reserve of soil moisture and optimize the sowing time at its maximum value.

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