

Modeling of water and salt transfer in the initial period of plant development

Aliakbar Khojiyev^{1*}, *Rustam Muradov*¹, *Shakhnoza Khojiyeva*², *Khurshida Yakubova*¹

¹Tashkent institute of irrigation and agricultural mechanization engineers, Tashkent, Uzbekistan

²Tashkent pharmaceutical institute, Tashkent, Uzbekistan

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) sharp recession of humidity of soil in the root zone.

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. Depending on their behavior, the need for appropriate ameliorative impacts on the agricultural field is established [14, 16, 17, 19, 20].

At this stage, it is necessary to use mathematical models for soils most common in the region with the aim of reclamation. 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, because soils must be considered as a multiparameter and dynamically changing object.

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 [1, 2, 5, 6, 11, 12, 15, 18].

^{1*} Corresponding author: aliakbar-x@mail.ru

2 Methods

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

On the demonstration sites, 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 2017-2018.

The experiment consists of two parts: The first is the analysis of soil moisture dynamics 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 top soil - from 0.5 and 5-10 cm layers. The sampling arrangement is shown in Fig. 1.

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 [1, 2, 7, 8, 9, 10].

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.:

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 [1, 2, 3, 5].

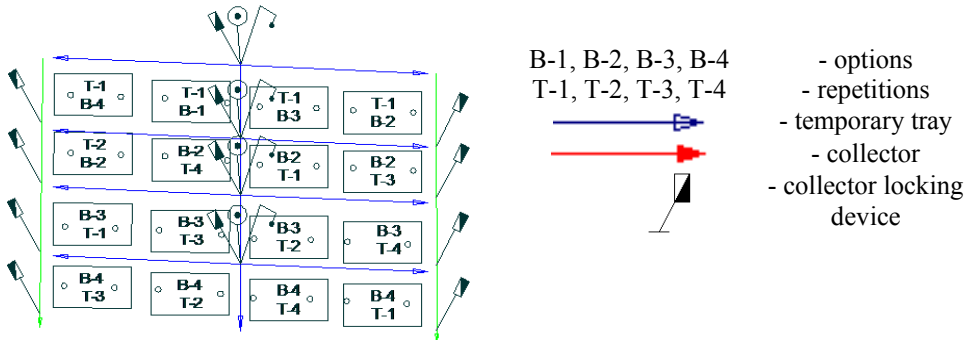


Fig-1. Experimental schemes for research sites.

$$\begin{cases}
 0 \leq z \leq z_1 \\
 \frac{d}{dz} \left[D_1(W_1) \frac{dW_1}{dz} \right] - \frac{dK_1(W_1)}{dz} = 0, \\
 \frac{d}{dz} \left[D_{N_1}(W_1) \frac{dN_1(W_1)}{dz} \right] - \frac{dV_{N_1}(W_1)}{dz} = 0, \\
 z_1 \leq z \leq L \\
 \frac{d}{dz} \left[D_2(W_2) \frac{dW_2}{dz} \right] - \frac{dK_2(W_2)}{dz} = 0, \\
 \frac{d}{dz} \left[D_{N_2}(W_2) \frac{dN_2(W_2)}{dz} \right] - \frac{dV_{N_2}(W_2)}{dz} = 0
 \end{cases} \quad (1)$$

$$W_1(0) = W_{IM} = const, \tag{2}$$

$$N_1(0) = N_{IM} = const \tag{3}$$

$$W_1(Z_1) = W_2(Z_1) \tag{4}$$

$$N_1(Z_1) = N_2(Z_1) \tag{5}$$

$$\left[K_1(W_1) - D_1(W_1) \frac{dW_1}{dz} \right]_{Z=Z_1} = \left[K_2(W_2) - D_2(W_2) \frac{dW_2}{dz} \right]_{Z=Z_1} \tag{6}$$

$$V_{N_1}(W_1) - D_{N_1}(W_1) \frac{dN_1(W_1)}{dz} \Big|_{Z=Z_1} = V_{N_2}(W_2) - D_{N_2}(W_2) \frac{dN_2(W_2)}{dz} \Big|_{Z=Z_1} \tag{7}$$

$$W_2(L) = W_{MC}, \tag{8}$$

$$N_2(L) = N_{MC} \tag{9}$$

where the following designations are entered for the arable and sub-plow layers, respectively: W_1, W_2 are volumetric humidity; coefficients of moisture conductivity are adopted in the form [1; 4]:

$$K_1(W_1) = A_1 e^{A_2 z}, K_2(W_2) = B_1 e^{B_2 z} \tag{10}$$

the speed of water movement in the ground is taken as [1]:

$$V_{N_1} = R_1 e^{R_2 Z}, \quad V_{N_2} = P_1 e^{P_2 Z} \tag{11}$$

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

$$D_1(W_1) = D_1 = const, \quad D_2(W_2) = D_2 = const \tag{12}$$

$$D_{N_1}(W_1) = D_{N_1} = const, \quad D_{N_2}(W_2) = D_{N_2} = const, \tag{13}$$

where: L is groundwater depth, m;
 Z_1 is boundary between arable and subsoil layers, m;
 W_{IM} is some intermediate moisture capacity between wilting moisture W_3 and the maximum moisture capacity W_{MMC} , t.e.

$$W_3 < W_{IM} < W_{MMC} \tag{14}$$

where: W_{MC} is full moisture capacity;
 Z is vertical coordinate directed down from the earth's surface.

Also, N_{IM} 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.

$$N_W \leq N_{IM} \leq N_S \tag{15}$$

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

$$\begin{cases} D_1 \frac{d^2 W_1}{dz^2} - A_1 A_2 e^{A_2 Z} = 0 \\ D_{N_1} \frac{d^2 N_1}{dz^2} - R_1 R_2 e^{R_2 Z} = 0 \\ D_2 \frac{d^2 W_2}{dz^2} - B_1 B_2 e^{B_2 Z} = 0 \\ D_{N_2} \frac{d^2 N_2}{dz^2} - P_1 P_2 e^{P_2 Z} = 0 \end{cases} \quad (16)$$

$$A_1 e^{A_2 Z} - D_1 \left. \frac{dW_1}{dz} \right|_{Z=Z_1} = B_1 e^{B_2 Z} - D_2 \left. \frac{dW_2}{dz} \right|_{Z=Z_1}, \quad (17)$$

$$R_1 e^{R_2 Z} - D_{N_1} \left. \frac{dN_1}{dz} \right|_{Z=Z_1} = P_1 e^{P_2 Z} - D_{N_2} \left. \frac{dN_2}{dz} \right|_{Z=Z_1} \quad (18)$$

where $A_1, A_2, B_1, B_2, D_1, D_2, R_1, R_2, P_1, P_2, D_{N_1}, D_{N_2}$ are some constants determined by comparing the analytical solution with the experimental data [1];
 Integrating the first equation of system (16), we will successively find

$$\begin{aligned} \frac{d^2 W_1}{dz^2} - \frac{A_1 A_2}{D_1} e^{A_2 Z} &= 0 \\ \frac{dW_1}{dz} &= \frac{A_1}{D_1} e^{A_2 Z} + C_1 \\ W_1 &= \frac{A_1}{A_2 D_1} e^{A_2 Z} + C_1 z + C_2 \end{aligned} \quad (19)$$

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

$$N_1 = \frac{R_1}{R_2 D_{N_1}} e^{R_2 Z} + C_3 z + C_4, \quad (20)$$

$$W_2 = \frac{B_1}{B_2 D_2} e^{B_2 Z} + C_5 z + C_6 \quad (21)$$

$$N_2 = \frac{P_1}{P_2 D_{N_2}} e^{P_2 Z} + C_7 z + C_8 \quad (22)$$

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

$$C_2 = W_{IM} - \frac{A_1}{A_2 D_1}, \tag{23}$$

We also determine C4 from the conditions (3) and (26)

$$C_4 = N_{IM} - \frac{R_1}{R_2 D_{N1}} \tag{24}$$

Based on (6) and (7), we find the relation

$$C_5 = C_1 \frac{D_2}{D_1} \tag{25}$$

$$C_7 = C_3 \frac{D_{N2}}{D_{N1}} \tag{26}$$

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

$$W_{MC} = \frac{B_1}{B_2 D_2} e^{B_2 L} + C_5 L + C_6 \tag{27}$$

$$N_{MC} = \frac{P_1}{P_2 D_{N2}} e^{P_2 L} + C_3 \frac{D_{N2}}{D_{N1}} L + C_8 \tag{28}$$

The dependence of C6 on C1 is found from (24) with allowance for (22)

$$C_6 = W_{MC} - \frac{B_1}{B_2 D_2} e^{B_2 L} - C_1 \frac{D_2}{D_1} L \tag{29}$$

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

$$C_8 = N_{MC} - \frac{P_1}{P_2 D_{N2}} e^{P_2 L} - C_3 \frac{D_{N2}}{D_{N1}} L \tag{30}$$

3 Results and Discussion

Relation (4) with allowance for (21), (22), and (26) allows us to determine C1 from equality

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

From where we find

$$C_1 = \frac{W_{MC} - W_{IM} - \frac{A_1}{A_2 D_1} [e^{A_2 Z_1} - 1] - \frac{B_1}{B_2 D_2} [e^{B_2 L} - e^{B_2 Z_1}]}{\frac{D_2}{D_1} [L - Z_1] + Z_1}, \quad (31)$$

It is possible to establish the value of C3 from equation (22), (23), and (27)

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

Hence we find

$$C_3 = \frac{N_{MC} - N_{IM} - \frac{R_1}{R_2 D_{N_1}} [e^{R_2 Z_1} - 1] - \frac{P_1}{P_2 D_{N_2}} [e^{P_2 L} - e^{P_2 Z_1}]}{\frac{D_{N_2}}{D_{N_1}} [L - Z_1] + Z_1}, \quad (32)$$

Substituting the values of arbitrary C₁, C₂, C₃ and C₄ in (19) and (20), we obtain the distribution of volumetric moisture and salt concentration in the arable layer as a function of z.

$$W_1 = W_{IM} + \frac{A_1}{A_2 D_1} [e^{A_2 Z} - 1] + \left[\frac{W_{MC} - W_{IM} - \frac{A_1}{A_2 D_1} [e^{A_2 Z_1} - 1] - \frac{B_1}{B_2 D_2} [e^{B_2 L} - e^{B_2 Z_1}]}{\frac{D_2}{D_1} [L - Z_1] + Z_1} \right] z \quad (33)$$

$$N_1 = N_{IM} + \frac{R_1}{R_2 D_{N_1}} [e^{R_2 Z} - 1] + \left[\frac{N_{MC} - N_{IM} - \frac{R_1}{R_2 D_{N_1}} [e^{R_2 Z_1} - 1] - \frac{P_1}{P_2 D_{N_2}} [e^{P_2 L} - e^{P_2 Z_1}]}{\frac{D_{N_2}}{D_{N_1}} [L - Z_1] + Z_1} \right] z \quad (34)$$

$$0 \leq z \leq Z_1$$

The definite values of the constants C₅, C₆, C₇, and C₈ 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.

$$W_2 = W_{MC} - \frac{B_1}{B_2 D_2} (e^{B_2 L} - e^{B_2 Z}) - \left(\frac{W_{MC} - W_{IM} - \frac{A_1}{A_2 D_1} [e^{A_2 Z_1} - 1] - \frac{B_1}{B_2 D_2} [e^{B_2 L} - e^{B_2 Z_1}]}{[L - Z_1] + Z_1} \right) (L - z) \quad (35)$$

$$N_2 = N_{MC} - \frac{P_1}{P_2 D_{N_2}} (e^{P_2 L} - e^{P_2 Z}) - \left(\frac{N_{MC} - N_{IM} - \frac{R_1}{R_2 D_{N_1}} [e^{R_2 Z_1} - 1] - \frac{P_1}{P_2 D_{N_2}} [e^{P_2 L} - e^{P_2 Z_1}]}{[L - Z_1] + Z_1} \right) (L - z) \quad (36)$$

$$Z_1 \leq z \leq L$$

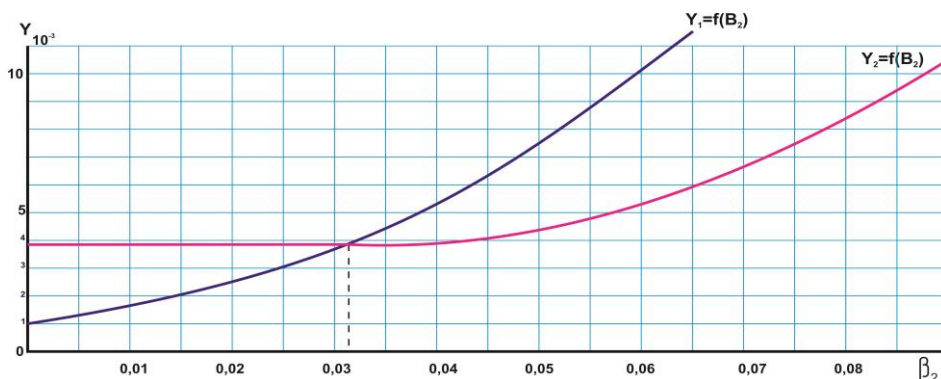


Fig 2. Determination of the value of β_2 by the transcendental equation.

The change in moisture content and concentration of salts at various initial surface moisture indices without considering the development of the plant root system for the conditions of the WUA "Uzbekistan" in the Syrdarya region is shown in Fig. 2. Determination of the constants was carried out according to the acad. F.B. Abutaliev given in [1, 2]. Fig. 2. 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 cm).

4 Conclusions

1. The developed models (33) - (34) can be used to calculate 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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