MODELING MOISTURE DYNAMICS IN THE IRRIGATED AREAS

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Abstract: Water is an essential resource, especially in arid contrives such as Uzbekistan and most parts of Central Asia. Investigation of moisture alterations at different environment was carried out more than 7 years period in Uzbekistan and Commonwealth Independent States (Kazakhstan, Tajikistan and Turkmenistan). 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 an irrigation and drainage; (3) sharp recession of humidity of soil in the root zone.

Key words: moisture transition, drainage system, underground water table.

Introduction

Nowadays irrigated agriculture consumes the greatest part of water resources, thus developing more exact and mathematically proved methods for forecasting and managing soil moisture in water scarcity period became significant issues. Water – as moisture, has essential role in all biochemical processes of plants, all vital processes, occurring in a vegetative organism, can proceed normally only under condition of sufficient saturation of cages by a moisture.

Water comes to plants from soil through their root systems. Soil is complex anisotropic porous environment in which there is a whole complex of the interconnected processes: absorption moisture in soil, infiltration and replenishment of subsoil waters, capillary water rising, moisture movement under the influence of temperature mode, etc. Dynamics of soil moisture define degree of its suitability for cultivation of various agricultural crops. For getting maximum yield from crops it is necessary to create an optimum mode of humidity of soil, to correct them in a current of the irrigating period on the basis of biological features of a plant and water-physical properties of soils.

To date, the issues related to the physics of water inflow to the roots and its flow towards the conduction system has not been settled yet. Description of the fluid flow through root system is the most difficult. The main difficulty is associated with the necessity of proper description and mathematic formalization of physiological processes controlling a possible active mechanism of solution transfer along the roots. Given this, we are considering the case as the initial approximation when the roots are spread over the soil evenly and, hence, change of moisture is associated with the moisture absorption process which is determined by the plant transpiration rate. Such researches were carried out in the Agrophysical Institute under the leadership of Academician S.F. Nerpin (Arakelyan et al., 1971, p. 3-10; Arakelyan et al., 1971, p. 56-64; Nerpin, 1975; Nerpin et al., 1976, p. 40-43).

Materials and methods

The research areas. The experiment was conducted in Surkhandarya, Sirdarya and Tashkent regions of Uzbekistan. The Surkhandarya investigation site is located in Surkhan-Sherabad Steppe Area (Kumkurgan) which is 58 km westwards of Termez city. The pilot site is situated at the terrace of Surkhandarya and irrigated with water from Sherabad Main Canal. According to the monitoring data, annual precipitation is scant and about about 280-320 mm. The area remains with a special temperate desert land, higher temperature and dry season, the annual average temperature at pilot site is 13.1-13.5°C. The hottest month in a year is July, has an average temperature of 30.2 °C, while the coldest month is January, and has an average temperature of - 6.1°C. The annual evaporation is 3300-4200 mm and relative humidity is 45-55 %. Irrigated area is mainly composed of sandy soil.
The Sirdarya investigation site is located in Mirza chul Desert. It is 15 km westwards of Gulistan – Sirdarya Region center. The study area is belonging to Mirzachul Desert and water for irrigation comes from Sirdarya River. In compliance with the monitoring data, annual precipitation is scant and 310-380 mm. The area remains with a special temperate desert land, higher temperature and dry season, the annual average temperature at pilot site is 9.7-12.4°C. The hottest month in a year is July, has an average temperature of 28.6 °C, while the coldest month is January, and has an average temperature of -5-7°C. The annual evaporation is 2900-3800 mm and relative humidity is 50-65 %. The ground surface is mainly composed of shifting sands dominated by fine sand.

The next investigation site is located in middle of Uzbekistan, the Tashkent investigation site is located at Chirchik-Ahangaran terrace, which is 54 km eastwards of Tashkent city and irrigated with water from Chirchik River. According to the monitoring data, annual precipitation is scant and about 380-420 mm. The area remains with higher temperature and dry season, the annual average temperature at pilot site is 10.5-13.7°C. The hottest month in a year is July, has an average temperature of 28-29.5 °C, while the coldest month is January, and has an average temperature of -3.8°C. The annual evaporation is 2900-3400 mm, relative humidity is 40-55% in May-October and 57-74% November-April. Irrigated area is mainly composed of loamy sand (Duan et al., pp. 63-67; Yin et al., 2003, pp. 62-68).

**Experimental method**

The spatial-temporal dynamics of soil moisture were investigated in several Water Consumers Association (Fig. 1).

![Figure 1: Research fields location](image)

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 2008-2011.

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 were 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. 2.
Calculation method

Moisture (M) was calculated to determine the profile of the volumetric water content (Vs) of soil (Nerpin, Kuznetsov, 1980, pp. 33-36). Both M and the soil water deficit amount (DWC) are defined by

\[ M = V_s H \times 10 \]  
\[ DWC = SFC - WC \]

where \( V_s \) 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 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.

Results and analysis

Simulation of the evaporation processes and moisture travel at the upper horizons of soil profile

In the work by Academicians F.B. Abutaliev and M.B. Baklushin (Abutaliev, Baklushin, 1974, pp. 47-49; Dukhovny et al., 1979), the moisture change at the presence of root, topsoil, and subsurface layers are given by:

\[
\frac{d}{dz} \left[ D_1(W_1) \frac{dW_1}{dz} \right] - \frac{dK_1}{dz} \frac{12E_t}{7(\delta+u_*)} \left[ 1 - \frac{z}{2(\delta+u_*)} - \frac{z^2}{2(\delta+u_*)^2} \right] = 0, \quad (0 \leq z \leq \delta + u_*)
\]

\[
\frac{d}{dz} \left[ D_1^*(W_1^*) \frac{dW_1^*}{dz} \right] - \frac{dK_1^*}{dz} = 0, \quad (\delta + u_* \leq z \leq z_1)
\]

\[
\frac{d}{dz} \left[ D_2(W_2) \frac{dW_2}{dz} \right] - \frac{dK_2}{dz} = 0, \quad (z_1 \leq z \leq L)
\]

Where \( W_S \) is surface moisture; \( W_{IS} \) is the initial distribution of volumetric water content over the land surface; \( W_{UFC} \) is ultimate field capacity; \( W_{FC} \) is field capacity; \( W_{WP} \) is wilting point; \( z \) is the vertical coordinate directed from the land surface downward; \( t \) is time; \( W_1 \) is the distribution of volumetric water content within the plant root system, allowing for its length (\( \delta \)) and possibility of moisture suction from the lower horizon (\( u_* \)). \( W_1^*(x,z,t) \) is the volumetric water content in the topsoil located between the root (\( \delta+u_* \)) and subsurface layers (\( z_1 \)). \( W_2(x,z,t) \) describes the moisture change in the subsurface layer.

\[
W_1(z)_{z=0} = W_{IP} = \text{const};
\]

\[
W_1(\delta + u_*) = W_1^* (\delta + u_*);
\]

\[
W_1^*(z_1) = W_2(z_1);
\]

\[
W_2(L) = W_{IP} = \text{const}
\]

\( K_1(x,z,t), K_1^*(x,z,t), K_2(x,z,t) \) are the coefficients of the soil hydraulic conductivity in appropriate layers. \( K_2(x,z,t) \) reaches its maximum value, i.e. permeability (filtration) coefficient \( K_{2z} \), on the groundwater table (GWT) below which the environment is supposedly fully saturated with moisture.

\[
\left[ K_1(W_1) - D_1(W_1) \frac{dW_1}{dz} \right]_{z=\delta+u_*} = \left[ K_1^*(W_1^*) - D_1^*(W_1^*) \frac{dW_1^*}{dz} \right]_{z=\delta+u_*}
\]
\[
\left[ K_1^*(W_1^*) - D_1^*(W_1^*) \frac{dW_1^*}{dz} \right]_{z=Z_i} = \left[ K_2^*(W_2^*) - D_2^*(W_2^*) \frac{dW_2^*}{dz} \right]_{z=Z_i}
\] (9)

The hydraulic conductivity coefficient for the root zone and top soil layer will be given by (Voronov N.V., 1987):

\[ K_1^*(W_1^*) = A_i e^{A_i z}, \quad K_2^*(W_2^*) = B_i e^{B_i z} \] (10)

After having solved the equation (3) by implementing (4), the moisture in the root layer will eventually take the form (Muradov, 2012, pp. 69-73):

\[
W_1(z) = W_{inp} + \frac{A_i}{A_2D_1} \left[ e^{A_i z} - 1 \right] + \frac{A_i z^2}{D_1} \left[ 1 - \frac{z}{12U} - \frac{z^2}{24U^2} \right] + D_1^*D_2^* \frac{\Phi}{P} z \quad 0 \leq z \leq \delta + u_*
\]

\[
W_1^*(z) = \frac{A_i}{A_2D_1} \left[ e^{A_i z} - e^{A_i (\delta + u_*)} \right] + \left[ D_1 D_2^* \frac{\Phi}{P} + \frac{7A_i (\delta + u_*)}{12D_1^*} \right] + \frac{A_i}{A_2D_1} \left( e^{A_i (\delta + u_*)} - 1 \right) + \\
+ W_{inp} \frac{3A_i}{8D_1} (\delta + u_*)^2 + \left[ (D_1^* - D_1) D_2^* \frac{\Phi}{P} - \frac{7A_i (\delta + u_*)}{12D_1^*} \right] (\delta + u_*)
\]

\[
\delta + u_* \leq z \leq z_1
\]

\[
W_2(z) = W_{inp} - \frac{B_i}{B_2D_2} \left( e^{B_i z} - e^{B_i L} \right) + (L - z) \left[ D_1 D_2^* \frac{\Phi}{P} + \frac{7A_i (\delta + u_*)}{12D_2^*} \right], \quad z_1 \leq z \leq L
\]

Results of the investigation of the moisture dynamics in automorphic soils allowing for the development of the root system

As shown in Fig. 3, upon the completion of water application, moisture is profusely consumed in the root system spread zone, then with the lapse of time the moisture decreases because of lowered GWT. Comparison of the calculation results with the experimental data has shown their satisfactory fit.

![Fig. 3. Dynamics of moisture change at drainage: case study of the Water Users’ Association (WUA) “Yangiobod”](image-url)
According to the results of the studies carried out in the WUAs on Uzbekistan, the soil moisture on the land surface decreases somewhat faster than in other parts of the subsurface area. At that, minimum moisture is observed at the boundary between the root and subsurface layers. The experiments proved the effectiveness of deep ripping instead of usual ploughing, which facilitates not only dramatic decrease of salts but also moisture retention during the vegetation period.

Analysis of figure 3 also provided information about moisture management by stage by stage loosening in water shortage period.

Table 1

Factors for the determination of moisture transfer dynamics in the stratified porous medium including root, topsoil, subsurface zones, and free surface of groundwater (Averianov, 1972; Duan et al.; Muradov, 2012; Yin, 2003)

<table>
<thead>
<tr>
<th>WUC and soil texture</th>
<th>Absolute terms of equation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$A_1 \times 10^{-4}$</td>
</tr>
<tr>
<td><strong>Surkhandarya Region Qumqurgan District</strong></td>
<td></td>
</tr>
<tr>
<td>Beshkahramon (Loamy clay)</td>
<td>3.34</td>
</tr>
<tr>
<td>Ogoppichigay (Medium loam)</td>
<td>5.64</td>
</tr>
<tr>
<td>N. Mirzoy (Sandy loam)</td>
<td>3.73</td>
</tr>
<tr>
<td><strong>Sirdarya Region Mirzaabad District</strong></td>
<td></td>
</tr>
<tr>
<td>Yangiabad (Loamy clay)</td>
<td>2.18</td>
</tr>
<tr>
<td>Amir Temur (Medium loam)</td>
<td>2.25</td>
</tr>
<tr>
<td>Gulistan (Sandy loam)</td>
<td>3.23</td>
</tr>
<tr>
<td><strong>Tashkent Region Qyvi Chirchik District</strong></td>
<td></td>
</tr>
<tr>
<td>Qorasuv (Loamy clay)</td>
<td>2.07</td>
</tr>
<tr>
<td>Akkuvsuygan (Medium loam)</td>
<td>2.34</td>
</tr>
<tr>
<td>Sayram suyi (Sandy loam)</td>
<td>3.44</td>
</tr>
</tbody>
</table>

Analysis of the given diagram demonstrates the volumetric water content decrease process against the background of horizontal drainage operation, which allows optimizing the time and depth of performing stepwise layer-by-layer ploughing against the background of horizontal drainage.

Fig. 3 shows the moisture distribution across the soil depth; the bends on the diagram indicate the boundary between the suction zone and subsurface layer. Soil moisture lowers in the root layer (0-15 cm), rises in the subsurface one (15-40 cm) and reaches its maximum at GWT (2.5 m).

**Conclusions and discussions**

The limitedness of water resources requires even more scientifically justified methods for the prediction of moisture change taking into account agricultural techniques and land reclamation measures being used. The correctness of joint actions and organizational countermeasures aimed at overcoming drought and control of irrigation water deficit depends on the moisture dynamics prediction accuracy on an irrigated area.

Based on the results of the researches we have drawn the following conclusions:

1. The developed equation for prediction soil moisture is proper for systematic open and closed subsurface horizontal drainage and allow for the soil porosity, groundwater table, and infiltration intensity.

2. The proposed relations for the prediction of volumetric water content distribution taking into account agro-technical (deep ploughing, stepwise layer-by-layer ploughing, conventional soil treatment) and land reclamation (moisture recharge) measures being used on the irrigated field show high fit with the experimental data and can be used when optimizing these works taking into consideration different “scenarios”.
3. The analytical dependences obtained for broad introduction require that the inverse problem of physics in each case being analyzed to be solved.

References
Dukhovny, V.A. et al. (1979) *Horizontal drainage of irrigated lands*, Moscow: Koloss.