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Mathematical modeling of moisture infiltration in the soil during drip irrigation of a garden

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Abstract. This article presents long-term data of theoretical and field experimental studies using a low-pressure drip irrigation system for the apple variety the "Golden" in the Chirchik-Akhangaran valley for the first time. In the development of irrigation regimes for equipment and technology for drip irrigation of a garden, there is a great importance to determine amount of water infiltration into the soils of the active layer of the irrigated area. As a result of current research work, a mathematical modeling of the process of moisture inflation in the soil during drip irrigation of the garden has been developed.

1 Introduction

At present, due to the shortage of water resources, it is becoming extremely important to create innovative methods of equipment and technology for irrigating crops of on-farm irrigation systems of a new generation, modernizing the operation of crop irrigation technology. The Cabinet of Ministers of the Republic of Uzbekistan has developed a Program for the implementation of drip irrigation systems, designed for 2019-2020. President of the Republic of Uzbekistan Sh.M. Mirziyoyev pays great attention to the application of innovative methods for establishing resource-saving equipment and technology for irrigating cotton, orchards and other crops on irrigated lands of the Republic of Uzbekistan. At the same time, with the organization of domestic production of the corresponding equipment systems. The decision of the Government is aimed at the rational and economical use of water resources.

Drip irrigation allows to get a high yield of crops while saving up to 40-50% of irrigation water and a significant reduction in labor costs for irrigating the garden compared to traditional methods [1,2].

The development of innovative irrigation technology and technical means of a low-pressure drip irrigation system of domestic production, aimed at creating favorable conditions for the growth and development of the orchard, at increasing the productivity of irrigated lands, irrigation water, increasing the value of KIV, KPI, performance coefficient of on-farm irrigation systems is a task that allows solving issues sustainable priority economic growth of agriculture and water management of our country.

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– educational and scientific center of the Tashkent Institute of Irrigation and Agricultural Mechanization Engineers ("TIIAME" NRU);
– cotton fields and orchards and vineyards;
– educational and Research Center of the Ministry of Higher and Secondary
– special education of the Republic of Uzbekistan; orchards and vineyards;
In general, the area of crops covered by the studies of the low-pressure drip irrigation system is at least 60 ha.

The subject of research is to increase the reliability of a low-pressure drip irrigation system, to establish water flow rates depending on the size of irrigation rates and the diameter of the dropper tubes, to determine the required minimum water pressure in the dropper tubes at different flow turbidity, to establish the optimal length of the dropper tubes depending on the slopes of the land surface, development of mathematical modeling of recommendations for the irrigation regime and irrigation technology for cotton, orchards based on a low-pressure drip irrigation system[6,7,8].

2 Materials and methods

When conducting research, generally accepted methods were used URICPAY, RIIVP, TIIAME, RRIHAM after the name of Kostyakov.
Moscow State Agrarian University. K.A. Timiryazeva and others. Representativeness was determined by the method of V.V. Shabanov, E.P. Rudachenko and the reliability of the results was verified by methods of mathematical statistics.

3 Results and discussions

In the theory of moisture transfer, Darcy's law is widely used to express filtration in the unsaturated zone, which has the form:

$$V = -K_w \left(\frac{d\varphi}{dz} - 1 \right) \tag{1}$$

Where V-rate of the infiltration;
K_w - coefficient of moisture conductivity depending on soil moisture;
φ - capillary potential of soil moisture;
z - downward coordinate, measured from the surface of the earth.

The moisture-conductivity coefficient of the soil, which determines the gravitational moisture transfer, is determined by the well-known formula of S.F. Averyanov:

$$K_w = K_\phi \left(\frac{w_i - w_0}{m - w_0} \right)^n \tag{2}$$

where K_ϕ - soil filtration coefficient at full saturation;
w_i - initial moisture of the soil;
w_0 - the content of bound moisture per unit volume of soil, taken equal to the maximum molecular moisture capacity;
m - porosity or total moisture content;
n - parameter depending on soil properties.

There are a number of assumptions on the nature of the relationship between humidity and moisture potential, of which the most common is the proposal by I.S. Pashkovsky and V.E. Chulaevsky expression [1-3].

$$\varphi = h_k \ln\left(\frac{w_i - w_0}{m - w_0}\right)^{-1} \tag{3}$$

Where : $h_k = \int_0^1 \varphi \cdot d\theta$ maximum capillary height.

Substituting the expressions as $n = 1$ и $\theta = (w_i - w_0)/(m - w_0)$; where $\theta = \theta(z,t)$ – (soil moisture content) in the equation, we will get:

$$V = -K_\phi \cdot \theta\left(\frac{d\varphi}{dz} \cdot \frac{d\theta}{dz} - 1\right) \tag{4}$$

expressing $d\varphi / d\theta$ through h_k / θ get:

$$V = -K_\phi \cdot \theta\left(\frac{d\varphi}{dz} \cdot \frac{d\theta}{dz} - 1\right) = K_\theta \cdot h_k \frac{d\theta}{dz} + K_\phi \cdot \theta \tag{5}$$

Enterμin the equation:

$$V = -\mu \cdot \frac{K_\phi \cdot h_k}{\mu} \cdot \frac{d\theta}{dz} + \eta \frac{K_\phi}{\mu} \cdot \theta \tag{6}$$

Expressing constant values as $K_\phi \cdot h_k / \mu = D$ и $K_\phi / \mu = B$ will get:

$$V = -\mu \cdot D \cdot \frac{d\theta}{dz} + \mu \cdot B \cdot \theta \tag{7}$$

Dividing both sides of the equation to $\mu$and designate$V / \mu = \overline{V}$ we will rewrite the equation as:

$$\bar{V} = -D \frac{d\theta}{dz} + B \cdot \theta \tag{8}$$

R.E.Horton recommends the rate of infiltration$V$as a function of t time:

$$V_t = (V_0 - K_\phi) \cdot \exp\left(-\frac{в}{z_o} \cdot t\right) - K_\phi \tag{9}$$

The water permeability of the soil is estimated for two periods: infiltration and filtration. The complete mathematical interpretation of infiltration was given by Kostyakov. For the characteristics of this complex process, indicators are proposed, m/h: $K_1 = K_\phi \cdot t^\alpha$

where K_1 - rate of the infiltration at the end of first given time;

K_ϕ -settled infiltration rate (K-Darcy), m/h;

t -time, after which infiltration is completed and absorption becomes steady, h;

α - exponent of infiltration curve;

$$\alpha = \frac{\lg K_t - \lg K_\phi}{\lg t - \lg t_\phi} \quad (10)$$

where K_t - rate of infiltration at the time of t, m/h;

$$K_o = \frac{K_1}{1-\alpha} \quad (11)$$

where K_o - average absorption rate in the first unit of time (at the very beginning), m/h,

$$K_{cp} = \frac{K_o}{t^\alpha} \quad (12)$$

where K_{cp} - average rate at period of time t.
In logarithmic coordinates, the absorption curve during the period of infiltration $\left(K_t = \frac{K_1}{t^\alpha}\right)$ is a straight line $tgK_t = tgK_1 - \alpha tgt$

I.G. Aliev and N.F. Bonchkovsky recommend equation as $K_o = K_{cp}(10\Pi)^\alpha$

where $P = 0,5^{0,1694}$

$$K_{av} = \frac{K_1 t_1 + K_\theta t_2}{t} \quad (13)$$

Where K_{cp} – average absorption rate over the period of infiltration;

t_1 - infiltration time, m/h;

t_2 - filtration time, m/h.

According to this method, the values of soil water permeability were determined in the conditions of Chirchik of the Akhangaran valley when irrigating the garden.

On soils of medium mechanical composition (Table 1) of the experimental plot, the rate of water absorption into the soil at the end of the first hour at the beginning of the growing season was 0.04 m/h, in the middle - 0.034 m/h, the filtration coefficient was 0.015 and 0.011 m/h, respectively.

On (Table 2) experimental plot with soils of average mechanical composition, the rate of water absorption at the end of the first hour at the beginning of the growing season was 0.051 m/h, in the middle of the growing season - 0.042 m/h, the filtration coefficient was 0.017 and 0.014 m/h [8-10].

Table 1. The rate of water absorption into the soil at the beginning and middle of the growing season, m/h

Absorption time, h	Experimental site for drip irrigation	
	Rate of absorption time into soil, m/h	
	At the beginning	In the middle
0.5	0.084	0.064
1	0.056	0.042
2	0.034	0.028
3	0.024	0.022

4	0.021	0.019
5	0.020	0.018
6	0.019	0.017
7	0.018	0.015
8	0.017	0.015
9	0.017	0.014
10	0.017	0.014
11	0.017	0.014

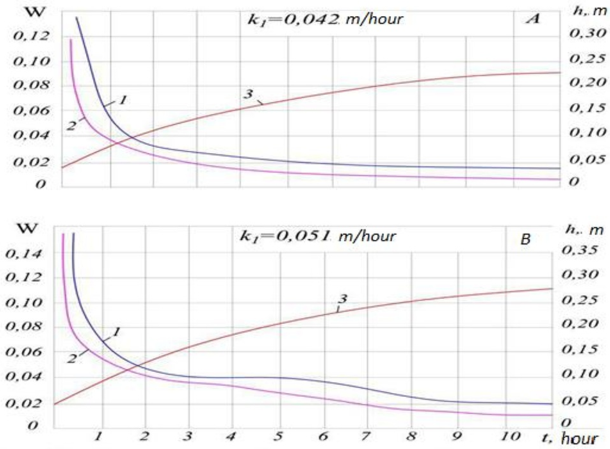

Fig. 1. The rate and layer of water absorption into the soil in the experimental plots: A-drip irrigation of the apple variety, "Golden", B-irrigation along the furrows of the orchard variety "Golden" (control variant).

In connection with the use of the irrigation rate as a factor of influence, we note that its value is determined by the ratio, that is, it depends on the productivity (flow rate) of the dropper and the duration of water supply. At the same time, the values of and can vary in significant ranges (ranging from 1 l / h to 12 and even 20 l / h, and can vary from (1-2) hours to 12 and even 24 hours). At the same time, due to the time factor (duration of water supply), by the end of drip irrigation, it is possible to fix different linear, area and volume dimensions of a single soil moisture contour [11-15].

Table 2. Formation and dynamics of the moisturizing circuit depending on the value of the irrigation rate during drip irrigation of the garden.

Pre-irrigation Humidity of soil, %	Humidification circuit parameters					
	Time after irrigation, day	Height of contour (H), m	Width of contour (L), m	Area of the contour (S), m^2	K_{ef}	K_{ef}^{av}
Irrigation norm 180 m^3 / ha						
75	0	1.23	0.63	0.70	1.90	1.84
	0.5	1.36	0.71	0.88	1.82	
	1	1.44	0.82	1.04	1.70	
	3	0.83	0.44	0.33	1.87	
	5	0.39	0,19	0.06	1,93	
Irrigation norm 120 m^3 / ha						
80	0	0.69	0.36	0.22	1.85	1.77
	0.5	0.87	0.49	0.39	1.73	

	1	1.00	0.60	0.55	1.63	
	3	0.45	0.22	0.10	1.86	
	5	0.25	0.12	0.03	1.77	

given Contour of moistening the root layer of the garden with drip irrigation.

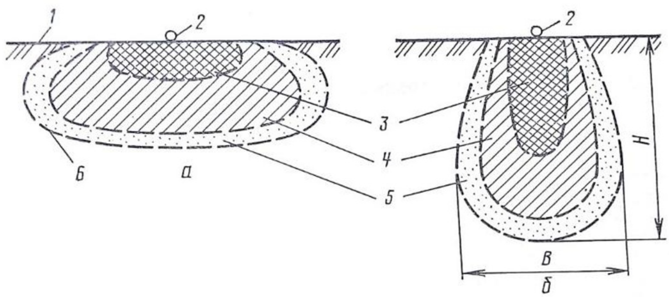

Fig. 2. and fig. 3. Characteristic humidification contours in drip irrigation:

a - on soils of medium mechanical composition; b- on soils of medium mechanical composition; 1-surface of the soil; 2-dripped micro water discharge; 3-center of over moisture soil; 4-center of normally moist soil; 5-center of partly moist soil; 6-dampening limit.

where A - modular area, ha; $\Delta t_{\min}$ - minimum watering period, days.

The number and layout of water supply points, the area of moistening depend on the type of crops and the water-physical properties of the soil.

The area moistened with droppers is calculated by the formula $A_{dr} = n_{dr} A_i / (a \cdot b)$

where n_{dr} - amount of drips per plant;

A_i - moistening area from one outlet, m^2;

$a \cdot b$ - planting chart, m^2.

4 Conclusions

1. The development of the irrigation regime, the technique and technology of drip irrigation, depend on the purpose of moisture infiltration into the soil and soil of the calculated layer of the garden.
2. For the first time, mathematical modeling of moisture infiltration into the soils of the calculated garden layer under drip irrigation has been developed. The value of the rate of infiltration (absorption) of water was equal at the beginning, in the middle of the first hour, at the end of the first hour and irrigation.
3.On the basis of many years of research work carried out on experimental plots located in the Chirchik-Akhangaran valley, a moistening circuit for the root system of the Golden apple tree was established with drip irrigation using a low-pressure system.

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