Mathematical calculations of water saving during furrow irrigation of cotton using a screen from an interpolymer complex

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Abstract. This article discusses the mathematical model of furrow irrigation to establish irrigation rates when watering cotton through a screen from an interpolymer complex (IPC) with the addition of mineral fertilizers. By the change in “I” when watering cotton through a surface screen from IPC with the addition of mineral equations, we can say that physically the effect of the screen will affect the amount and rate of infiltration “I” and “I”, other relations do not change. In the case of placing the screen in the form of a thin film (as experiments show), soil infiltration decreases by approximately 3-3.5 times.

1. Introduction
Issues of increasing the efficiency of the use of water and land resources and improving the reclamation conditions of lands specified in laws and resolutions of the Cabinet of Ministers of the Republic of Uzbekistan puzzled scientific organizations to work on improving methods and methods to increase the fertility of the land, through the proper use of minerals supplied during irrigation, which is the main factor in increasing the productivity of cotton.

It is known that mineralization occurs by the penetration of ions according to the law of osmosis in the soil and it should be noted that 13 elements are involved in this, including nitrogen, phosphorus, potassium, etc.

The recommendations for irrigated areas suggest the following ratios of nitrogen, phosphorus and potassium (NPK), as 1: 0.75: 0.35. Also, for the formation of a crop of 1 kg/ha, cotton receives from the soil 5.5 - 6.5 kg/ha of nitrogen, 2-2.5 kg/ha of phosphorus and 5-6 kg/ha of potassium, but regardless of the yield, cotton uses nitrogen in the comparison phase from 69% (1970) to 72% (2018), phosphorus from 42 to 48% and potassium about 3 times more, that is, from 35 kg/ha to 100 kg/ha.

The reason for such a decrease in the efficiency of the use of mineral fertilizers by cotton is that a significant part of the mineral fertilizers is filtered deeper below the calculated soil layer by irrigation water.
The aim of this work is to develop a mathematical model of furrow irrigation to establish the irrigation rate when watering cotton through the screen from the IPC with the addition of minerals (nitrogen, phosphorus or potassium) in the composition and establish the irrigation rate of cotton.

2. Method

The first attempts to describe the processes of running water through a furrow, and then draining the accumulated volume after stopping the water supply, used to calculate the elements of irrigation technology showed that the solutions presented on the balance equations [2] do not reflect the specifics of the proposed irrigation, which requires the creation of a mathematical model.

Mathematical modelling of furrow irrigation taking into account the anti-filter screen is based on the Sen-Venan equation [2]:

\[ \frac{\partial Q}{\partial t} + \frac{\partial (\partial Q)}{\partial x} + gF \frac{\partial h}{\partial t} + I \nu_x - gF (i_0 - i_f) = 0 \]  

(1)

\[ \frac{\partial Q}{\partial x} + \frac{\partial F}{\partial t} = I \]  

(2)

Water consumption in the furrow

\[ Q = \nu F \]  

(3)

Where;  
- \( t \) – time; \( \nu \) – flow rate;  
- \( F \) – furrow cross-sectional area;  
- \( \nu_x \) – relative rate of lateral inflow (or outflow) of infiltration;  
- \( g \) – gravity acceleration;  
- \( i_0 \) – downhill slope;  
- \( i_f \) – friction slope.

It should be noted that the intensity of infiltration "I" in the general case depends on the depth of the furrow and is described by the transport equation [2]:

\[ \frac{\partial I}{\partial t} = \frac{\partial}{\partial z} \left[ k(t, z) \frac{\partial I}{\partial z} \right] \]  

(4)

Where; \( z \)–coordinate along the depth of the soil layer, and the function \( k(t, z) \) reflects the filtration properties of the soil.

For many practical tasks, “I” is constant. For the total infiltration of water per unit length of the furrow, an empirical formula is adopted, for example, the A.N.Kostyukova equation [2,3]:

\[ Z = k \tau^\alpha + \mathcal{G}_T \tau \]  

(5)

Where: \( \tau \)– effective absorption time;  
- \( \alpha \) and \( k \) – empirical parameters;  
- \( \mathcal{G}_T \) – infiltration rate.

Thus, we can say that equation (1) expresses the relationship between the flow rate of water supply to the furrow (Q), infiltration (I) and the rate of infiltration (\( \mathcal{G}_T \)), height of the furrow filling \( h(t, x) \) as well as the slope of the furrow. To simplify the solution of equations (1) and (2), equations (1) are empirically replaced by the dependence

\[ Q = \alpha h^n \]  

(6)

Then equation (2) is simplified and takes the form:

\[ \frac{\partial h}{\partial t} + \alpha n h^{n-1} \frac{\partial h}{\partial x} = -I \]  

(7)

Equation (2) is actually an equation of continuity of fluid flow averaged over a vertical coordinate. Therefore, the intensity “I” is understood as the average intensity, and not the value “I” itself, obtained as a solution of equation (5) for the case of a constant value “I”, i.e. these two concepts are the same.
By the change in “I” when watering cotton through a surface screen from IPC with the addition of mineral equations, we can say that physically the effect of the screen will affect the amount and rate of infiltration “I” and “q”, other relations do not change [6]. In the case of placing the screen in the form of a thin film (as experiments show), soil infiltration decreases by approximately 3-3.5 times. Therefore, the calculation for this option must be done with “I”, reduced by the same amount.

Furrow irrigation with a subsoil screen in depth z=z₀ deserves separate consideration. To obtain the expression “I” for this option, it is necessary to solve equation (6) and then average the resulting solution over from 0 to z₀.

From experience it follows that in fields with an intra-soil screen at the bottom of the furrow, the intensity is the same in magnitude as with the usual condition, but at a depth z=z₀ it decreases in “n” times. When solving the boundary value problem for “I”, it is necessary to solve equation (5) with the following boundary conditions:

\[
\begin{align*}
I(z, t = 0) &= I_0 \\
I(t_0) &= I_0 \\
I(z_0, t) &= \frac{I_0}{n}
\end{align*}
\] (8)

The decision “I” is made in the form of the sum of the constant in time component “V (z)” and the perturbation “W (z, t)”:

\[
I(t, z) = V(z) + W(z, t)
\] (9)

An analytical solution of equation (10) is generally difficult, but there are various options for the numerical solution. In this case, one can do without solving equation (10) using elements of the furrow irrigation technique.

In the general case, solutions of a first-order quasilinear partial differential equation in the following form:

\[
a \partial_x + b \partial_y = c
\] (10)

Where: a, b, c–functions of x, y, θ and has a close relationship with the general solutions of its characteristics, described by the following ordinary differential equations [3]:

\[
\frac{\partial x}{\partial s} = a; \quad \frac{\partial y}{\partial s} = b; \quad \frac{\partial \theta}{\partial s} = c
\] (11)

Here: S - perimeter, for which one of the independent variables x or y can be selected. In relation to our case (b=I, a=2αh, θ=h) and choosing as \( \frac{\partial}{\partial S} = t \), we will get:

\[
\frac{\partial x}{\partial t} = 2αh
\] (12)

\[
\frac{\partial h}{\partial t} = -I
\] (13)

Here, the functions x, h are understood as functions of the parameter t, i.e.

\[ h = h[x(t), t] = h(t) \]

Integrating first (13), and integrating (12), we obtain the final result:

\[
x(t) = x(t_0) - \alpha \frac{2}{2} (t - t_0) \left[ 1 - \frac{(n - 1)}{2n} \right] l_0 + \frac{2I_0z_0(n - 1)}{\pi^2 k^4 n} \times \sum_{m=1}^{\infty} \frac{1}{(2m+1)^2} e^{-\frac{\pi(2m+1)^2}{x_0}k^2t} - e^{-\frac{\pi(2m+1)^2}{x_0}k^2t_0} + 3\sqrt{\alpha Q_0}
\] (14)

With a constant intensity of infiltration "I_0" equations (14) and (15) take the following form:

\[
\begin{align*}
h(t) &= h(t_0) - l_0(t - t_0) \\
x(t) &= x_0 - \alpha[h(t_0) + l_0 t - l_0 t_0]^2 + ah^2(t_0)
\end{align*}
\] (15)
Thus, we obtained an expression for calculating the value of infiltration during irrigation of cotton through the anti-filter screens from IPK, for various values of the depth of the calculated soil layer [7,8].

3. Results
The calculations obtained according to the results of field studies of irrigation through IPC screens with mineral fertilizers added to it and software for the computer implementation of the mathematical model are given in tables 1 and table 2.

| Shutters | Furrow length, m | \( t_{co} \), min. | Efficiency of using irrigation rate\((E_a)\), % | Uniform distribution of moisture over furrows (DU), % | D, mm. (1 mm = 10 m³/ha) |
|----------|------------------|---------------------|-----------------------------------------------|------------------------------------------------|-----------------------|
|          | Field researched. | Comp. data          | Field researched. | Comp. data | Field researched. | Comp. data |
| 1        | 18,3             | 46,8                | -                | -          | -                   | 101,3        | 102,5    |
| 2        | 38,1             | 97,4                | 87,9             | 86,5       | 71,3                | 72,0         | 101,7    | 102,3    |
| 3        | 55,6             | 139,1               | 87,7             | 86,5       | 80,8                | 82,0         | 101,1    | 100,1    |
| 4        | 70               | 178,3               | 86,8             | 85,5       | 81,4                | 82,2         | 100,9    | 101,9    |
| The average |                   |                     | 87,5             | 86,2       | 77,8                | 78,7         | 101,0    | 101,7    |

From the data in tables 1 and 2 it can be seen that the results of field studies on the calculation of the regime and operational characteristics of furrow irrigation, obtained under various conditions using anti-filter screens from the IPC, are confirmed by the software of the above and numerical methods for computer implementation of the mathematical model of the problem.

Water consumption = 0.0006 m³/sec; field slope = 0.002; Manning’s coefficient= 0.040; \( I_0 \) = 0.0066 m³/sec/m; \( D \)– irrigation rate, mm; watering time \((t_{co}) = 178,3\) min.

| Shutters | Furrow length, m | \( t_{co} \), min. | Efficiency of using irrigation rate\((E_a)\), % | Uniform distribution of moisture over furrows (DU), % | D, mm. (1 mm = 10 m³/ha) |
|----------|------------------|---------------------|-----------------------------------------------|------------------------------------------------|-----------------------|
|          | Field researched. | Comp. data          | Field researched. | Comp. data | Field researched. | Comp. data |
| 1        | 26               | 50,3                | -                | -          | -                   | 102,8        | 103,3    |
| 2        | 53               | 101,4               | 87,7             | 86,5       | 78,7                | 79,2         | 102,1    | 102,1    |
| 3        | 79               | 156,2               | 87,1             | 86,5       | 81,3                | 82           | 106,2    | 105,5    |
| 4        | 105              | 204,5               | 86,9             | 87,5       | 81,9                | 82,2         | 104,1    | 103,9    |
| The average |                   |                     | 87,2             | 86,8       | 80,6                | 81,1         | 103,8    | 103,7    |
Water consumption = 0.0008 m$^3$/sec; field slope = 0.002; Manning’s coefficient = 0.040; $I_o = 0.0066 m^3/c/m$; D– irrigation rate, mm; watering time($t_{co}$) =204.5 min.

4. Conclusion
A mathematical model based on the Sen-Venan equation for irrigating cotton through the surface and subsoil screens from the IPC was developed. Computer program has been implemented to calculate the mode and operational characteristics of furrow irrigation under various conditions.

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