A calculation model for determining the agricultural crops water consumption for resource-saving irrigation regimes

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Abstract. Scientific and technical progress in the development of land reclamation substantiates the urgent need in implementation of a new methodological approach for developing and implementing the processes for resource-saving water use in general, including irrigation of agricultural crops. The essence of the method is that all above-mentioned processes should be substantiated with the ecological-landscape approach methodology, taking into account progressive knowledge both in the accompanying natural sciences and in the reclamation industry that ensures minimal anthropogenic loads on the environment components and the creation of a healthy environmental situation in agricultural landscapes. Empirical dependences of various crops evapotranspiration and the actual moisture supply of the soil root layer have been determined for the corresponding phases of plant development by long-term experimental studies on the irrigation systems of the North Caucasus region for various soil and climatic irrigation zones, followed by comparison of the data obtained with the potential evapotranspiration data at the corresponding meteorological stations. Data analysis shows that the calculated absolute data values of the correlation coefficients between the compared values of the studied parameters vary in a wide range from 0.34 to 0.98, and obtained empirical dependencies are generally described by nonlinear mathematical equations. Comparison between the methods for determining the parameters under study has shown that calculation according to Alpatev gives significant errors; calculation according Kharchenko, while generally satisfactory, allows for unacceptable deviations in particular solutions; calculation according to the proposed model shows good results with acceptable deviations in all cases.

1. Introduction

Information and analytical analysis of special literature on practice of reclamation, both in Russia and abroad indicates the presence of various empirical dependencies for determining crop evapotranspiration, which are the critical factor in the expenditure part of the water balance equation for an irrigated field. The amount of evapotranspiration depends on a significant number of factors, both natural, including soil water-physical and chemical properties, actual hydrometeorological conditions, soil moisture, hydrological characteristics of irrigated areas of the corresponding irrigation
zones, and the physiological properties of plants, progressive technologies of their cultivation, taking into account reclamation technologies [1-4]. Scientific and technological progress in reclamation science development justifies the urgent need in application of a new methodological approach to the development and implementation of processes for resource-saving water use, including agricultural crops irrigation. The essence of the approach is that all the above-mentioned processes should be based on the environmental landscape approach methodology, taking into account the progressive knowledge both in the accompanying natural sciences and in the reclamation industry, which provides minimal anthropogenic loads on the natural environment components and the creation of a normal ecological situation in agricultural landscapes [5-7].

To determine the rational volumes of water supply to irrigated farms of various forms of ownership located in the service areas of irrigation systems of federal ownership, as well as to have a basis for their local regulation, it is necessary to establish a scientifically based model of crop evapotranspiration with a sufficient degree of accuracy, taking into account the plant development phases [8, 9].

2. Materials and methods
Analysis of the data obtained shows that, firstly, the calculated absolute values of the correlation coefficients between the compared values of the studied parameters vary over a wide range from 0.34 to 0.98. Thus, the most important regularity that substantiates the influence of hydrometeorological parameters and heat and moisture supply of the calculated soil layer on the amount of agricultural crops evapotranspiration has been determined. In general, the obtained empirical relationships are described by nonlinear mathematical equations. Secondly, the degree of influence of each hydrometeorological factor on the value of evapotranspiration and other studied parameters obtained in experimental plots of different soil and climatic irrigation zones was found, the accuracy degree of which is determined by the corresponding absolute value of the correlation coefficient. For example: “evapotranspiration – potential evapotranspiration”, $r = 0.96$ (the most reliable and accurate link); “crop yield - evapotranspiration” and “potential evapotranspiration”, respectively, $r = 0.86$ and $r = 0.76$ (good correlation and sufficient accuracy); “yield” - “irrigation rate”, $r = 0.51$ (very weak correlation and very insufficient accuracy) [10].

3. Results and discussion
The empirical dependences of crop evapotranspiration on the actual moisture supply of the root layer for the corresponding phases of plant development, followed by comparison of the data obtained with the data of potential evapotranspiration at the corresponding meteorological stations have been determined by experimental studies. The dependencies are plotted in relative values and are shown as an example in Figure 1 for alfalfa by phases: aftergrowth, budding and initial blossom. Generally, the empirical dependencies are described with a high degree of reliability ($r = 0.90$), parabola equations, with the corresponding empirical coefficients (Table 1), which has a general form:

$$\frac{ET}{E_o} = a_1 \cdot W_0 + a_2 \cdot W_0^2, \quad r = 0.90$$

where $ET$ is evapotranspiration, mm; $E_o$ is the potential evapotranspiration according to weather station data, mm; $W_0$ is the relative moisture reserves:

$$W_0 = \left( \frac{W_H + W_K}{2 \cdot W_{FC}} \right); \quad W_H, W_K, W_{FC}$$

are moisture reserves, respectively, initial, final and the ones corresponding to the lowest moisture capacity, mm; $a_1$ and $a_2$ are the corresponding empirical coefficients of the equation.
Figure 1. Dependence of evapotranspiration of perennial grasses on productive moisture reserves a - aftergrowth; b - budding; c – initial blossom.

Table 1. Empirical coefficients for determining the perennial grasses yield

| Crops          | Empirical coefficients |
|----------------|------------------------|
|                | $a$        | $a_1$     | $a_2$     |
| aftergrowth    | 0.190     | 0.585     | -0.037    |
| budding        | 0.038     | 2.30      | -1.17     |
| initial blossom| 0.186     | 1.74      | -0.63     |

To determine the unknown quantities in Formula 2, we take the evapotranspiration value using the water balance equation

$$ET = W_{W} - W_{K} + P + M + V_{gr} - V_{sp} - V_{u},$$

(2)

where $W_{W}, W_{K}$ are soil moisture reserves at the beginning and end of calculation period, mm,

$P$ is precipitation, mm

$M, V_{gr}, V_{sp}, V_{u}$ are respectively, the values of the irrigation rate, groundwater feeding, surface runoff, infiltration, mm

Evapotranspiration values according to the developed method (5) were compared with the generally accepted analytical dependences by A. M. Alpatiev and S. I. Kharchenko (formulas 3-5):

$$ET = K \cdot E_{w},$$

(3)

$$ET = \left( K_1 \cdot \left( \frac{W_{W} + W_{K}}{2 \cdot W_{FC}} \right) + K_1 \right) \cdot E_{w},$$

(4)
\[
ET = \left( a_0 + a_1 \cdot \left( \frac{W_H + W_K}{2 \cdot W_{FC}} \right) \right) + a_2 \cdot \left( \frac{W_H + W_K}{2 \cdot W_{FC}} \right)^2 \cdot E_w,
\]

(5)

where \(K, K_1, K_1'\) are the corresponding bioclimatic coefficients for the indicated models.

The comparison of the results of equations calculations (3–5) according to equation (2) was carried out by the standard methods of mathematical statistics with the obtained in-row correlation coefficients less than 0.5. The fulfillment of this condition indicates the independence of the terms of the data series and the legitimacy of using the calculation method (Fig. 2). Analysis of the calculated data shows that the deviation of the moisture reserves values in the calculated soil layer during the growing season, calculated by empirical relationship (3), differs from the actual values by 1.0 to 20.0%; according to dependence (4) the difference is by 0.5 to 10.0%; and according to dependence (5) is varies from 1.0 to 5.0%;

Figure 2. Comparison of actual \(W_{KA}\) and calculated \(W_{KC}\) final soil moisture reserves: \(a\) - equation 3; \(b\) - equation 4; \(c\) - equation 5; black and red lines indicate \(W_{KA} = W_{KC}\) and \pm 5\% of their equality, respectively.

The value of the quality criterion \(\eta\) determines the following classification of calculation methods in general: value \(\eta \leq 0.5\) - the calculation method is good with acceptable deviations of the calculated values; \(0.5 < \eta \leq 0.8\) - the calculation method is generally satisfactory with unacceptable deviations of the calculated values; \(\eta > 0.8\) - the method gives very significant errors in determining the calculated values in certain time periods.

4. Conclusion
It was found that the method for determining the parameters under study by equation (3) gives significant errors; the method according to equation (4) is satisfactory in general, but allows
unacceptable deviations in particular cases; the method according to equation (5) is good, with permissible deviations of the calculated values from the corresponding actual values. The correlation coefficients according to the equations were, respectively, $r = 0.34$; $r = 0.64$, $r = 0.95$.

The methodology for determining the evapotranspiration of agricultural crops based on the methodology of the ecological landscape approach, taking into account the probabilistic nature of hydrometeorological and water balance information, the use of progressive knowledge in the relevant natural sciences, has been scientifically substantiated, developed and implemented in wide production conditions of irrigation systems in the North Caucasus of various soil and climatic irrigation zones. This ensures permissible anthropogenic loads on the components of the environment and the creation of a right ecological situation in agricultural landscapes; a significant increase in the accuracy and reliability of planning and implementation of water use processes in irrigation systems, including the calculation and implementation of resource-saving irrigation regimes for agricultural crops, saving water and energy resources.

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