PROCEEDINGS OF THE YEREVAN STATE UNIVERSITY
УЧЕНЫЕ ЗАПИСКИ ЕРЕВАНСКОГО ГОСУДАРСТВЕННОГО УНИВЕРСИТЕТА
Geology and Geography **59**(2), 2025 *География и география*

Geography

УДК 631.587

DYNAMICS OF ESTIMATED EVAPOTRANSPIRATION AND HUMIDITY OF IRRIGATED SOILS IN ARMENIA

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The investigations are related to the development of the methods of total water demand estimation for the crops cultivated in the irrigated conditions of different agricultural zones. The agro-climatic indicators recorded in 2015–2019 by 10 hydrometeorological stations served as baseline data. The maximum crops water demand per decades has been calculated via CropWAT software. The soil moisture monitoring results enable to disclose the effect of various evapotranspirations on the moisture dynamics in the soil. The changing pattern of the crops total evaporation speed at different values of soil depth has been disclosed, while based on the mathematical processing of the experimental results, a calculated formula has been derived, which enables to solve the problem of crops coefficient calculation in non-standard conditions. The new mathematical model for the detection of moisture change in the soil, depicts the soil moisture regime more precisely, which enables to describe the dynamics of total evaporation from the soil and plant surfaces for the period of irrigation intervals in more precise manners.

https://doi.org/10.46991/PYSUC.2025.59.2.278

Keywords**:** reference crop evapotranspiration, FAO-56 methodology, crop evapotranspiration under non-standard conditions, crop coefficient, mathematical modeling.

Introduction. Along with a number of other factors, soil moisture regime predominantly ensures high and sustainable crop yield in irrigated lands [1, 2]. The soil moisture regime is affected by a number of factors, among which evaporation from soil and plants surface, crops irrigation regime, the depth of groundwater installation, the soil mechanical composition, crop species are of particular significance [3–8]. Extensive theoretical and experimental studies have been conducted in this branch, which aim to identify such a water regime for agricultural crops in the “ground water-soil-plant-air” system, in case of which sustainably high crop yield of desired quality can be harvested [1, 6, 9, 10]. Such a great number of research works is due to the fact that in addition to common properties the study results on the land water regime have also demonstrated local

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characteristics. The latter are primarily related to soil, climatic and hydro-geological conditions, as well as to the level of irrigated agriculture management [2, 11–13].

The influence of climatic factors on the dynamics of the soil water regime can be assessed by evaluating the estimated evapotranspiration, for which FAO-56 methodology developed on the basis of Penman Monteith's equation [7] is applicable.

However, the estimated evapotranspiration (ET_0), as a reference value, is not yet sufficient to assess changes in the soil moisture regime. This is the reason, why there is a transition from the values of maximum estimated evapotranspiration to the total evaporation determination ($ET_c = K_c \cdot ET_0$) from the plant-covered areas [14–19]. It is known that the crop coefficient is defined by determining the single- and two-factor coefficients. Usually, in case of two-factor approach, the evapotranspirations difference between the reference and cultivated land plot is estimated through the coefficient K_c .

With a two-factor approach, the K_c crop coefficient is divided into two components $K_c = K_{cb} + K_e$, according to which a comparative assessment of evapotranspiration is conducted [16, 17, 19, 20].

Since the results of our study are planned to use for irrigation planning and design works, the results of a single-factor approach are quite sufficient to solve the presented problem [3, 19].

The rate of evapotranspiration from the land and plant surface ET_c depends on the ET_0 and the soil mechanical composition, field maximum humidity (FMH), crops shade cover, as well as on other factors [4, 5, 22–24].

Such an approach will enable us to specify the values of evapotranspiration coefficient K_c and develop a new approach to implement analytical assessment in various conditions.

Materials and Methods. The aim of the research is to study the changes of crops estimated evapotranspiration in different zones of the Republic of Armenia depending on the effect of climate factors, and based on the obtained results to adjust the model of crops water demand calculation on the bases of changing patterns of soil moisture per the soil depth during the vegetation period. To achieve the mentioned goal the following problems have been enhanced and solved:

- studying the peculiarities of hydrometeorological stations' allocation in the territory of the Republic of Armenia and doing mapping thereof;
- collecting data on agro-climatic indices (relative air humidity, wind speeds, number of sunshine days, maximum and minimum air temperatures) from the hydrometeorological stations for 2015–2019;
- calculating estimated evapotranspirations through the method of FAO-56 developed on the bases of Penman-Monteith equation;
- estimating and analyzing the changing patterns of estimated evapotranspirations depending on the altitudes of hydrometeorological stations' allocation above the sea level;
- studying the changes in soil moisture supply per the depth of active soil layer during the vegetation period;
- establishing correlation between the soil moisture and estimated evapotranspiration.

To conduct the research, FAO-56 methodology, developed on the basis of the Penman Monteith's equation and a weighted method for soil moisture assessment have been used. The estimated evapotranspiration, depending on the agro-climatic parameters, has been calculated through the following formula:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}, \quad (1)$$

$$ET_c = (K_{cb} + K_e) \cdot ET_0 , \quad (2)$$

where ET_0 is the maximum evaporation value; R_n is radiation that has reached the crop surface; G is the radiation reflected from the soil surface; T is air temperature; e_s is saturated vapor pressure; e_a is actual vapor pressure; u_2 is wind speed; Δ is angular coefficient; γ is physical constant, $\gamma = 0.665 \cdot 10^{-3}P$; P is atmospheric pressure [19].

For crop-covered land plots the formula is:

$$ET_c = K_c \cdot ET_0, \quad (3)$$

where the values of the coefficient K_c are determined for single-factor and two-factor cases. For two-factor, the coefficient K_c is determined by the following equation:

$$K_c = K_{cb} + K_e, \quad (4)$$

$$K_{cb} = K_{cb(Tab)} + [0.04(U_2 - 2) - 0.004(RH_{\min} - 45)]\left(\frac{h}{3}\right)^{0.3}, \quad (5)$$

where K_{cb} is the basic coefficient of the plant (the values are tabularized in the bulletin FAO-56, and depending on the plant species we select the values from $K_{cb(Tab)}$; U_2 is the wind speed; $RH_{\min}$ is the minimum relative air humidity; H is the plant height [19].

K_e is determined upon the following condition:

$$K_e = K_r(K_{c\,\max} - K_{cb}) \le f_{ew}K_{c\,\max}, \quad (6)$$

where K_e *is* the coefficient characterizing evaporation from the soil surface; $K_{c\,\max}$ is the maximum value of K_c, which is considered after irrigation or rains; K_r is a parameter that does not have a measuring composition, characterizing the evaporation reduction from the lower soil layers; f_{ew} is the soil sector, where from water evaporates with maximum amounts due to high moisture content.

To determine the dependence of moisture evaporation from the soil and estimated evapotranspiration climatic indicators of 10 hydrometeorological stations for the last five years have been investigated.

Stations located at the altitude of 818–2064 *m* a.s.l. have been selected. The image of the stations location is shown in Fig. 1.

Upon the summarized results of the current materials and methods related to the planned research works it becomes obvious that the selected hydrometeorological stations selected for the estimation of total crops water demand describe the agroclimatic peculiarities of the irrigated lands of the Republic of Armenia and are typical for the study of irrigated farming conditions.

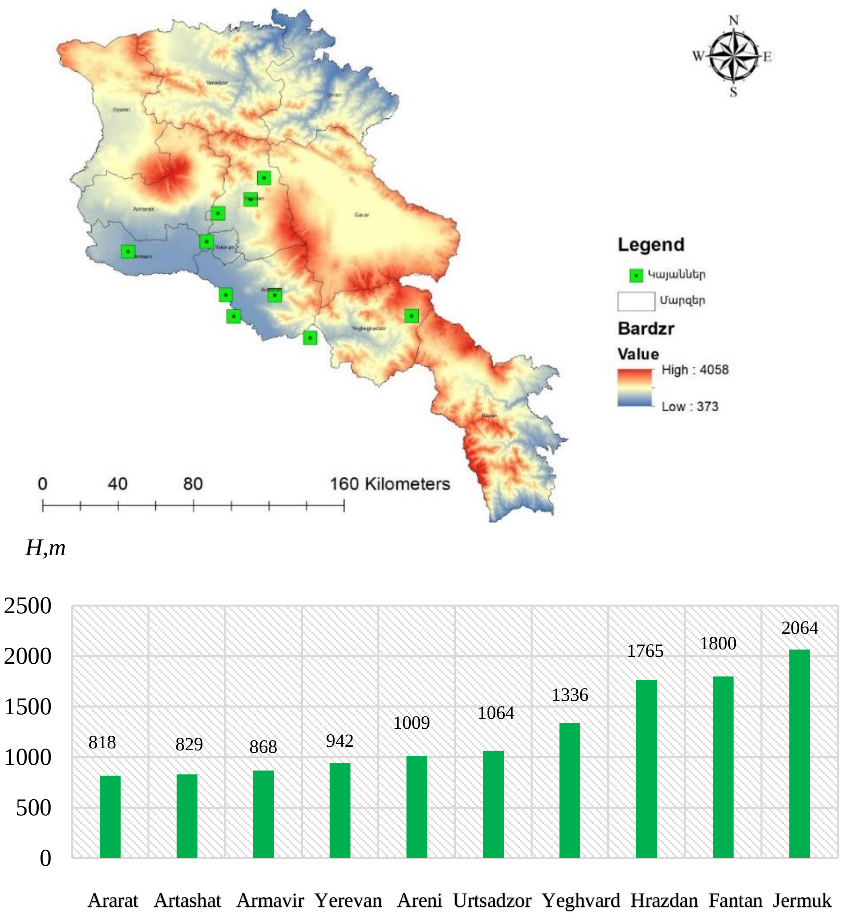
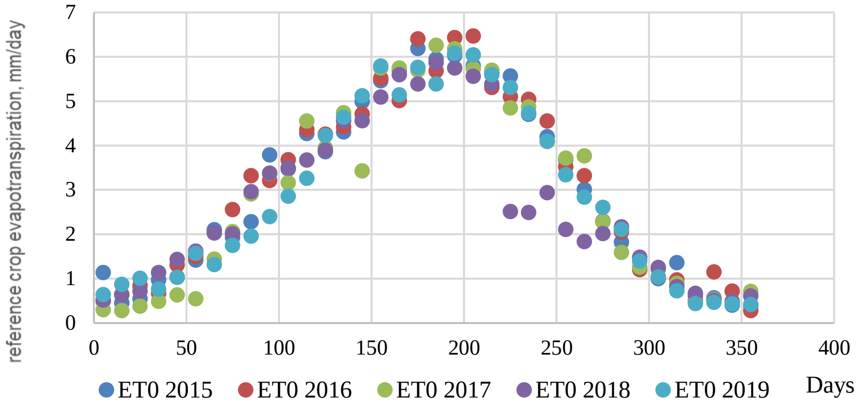


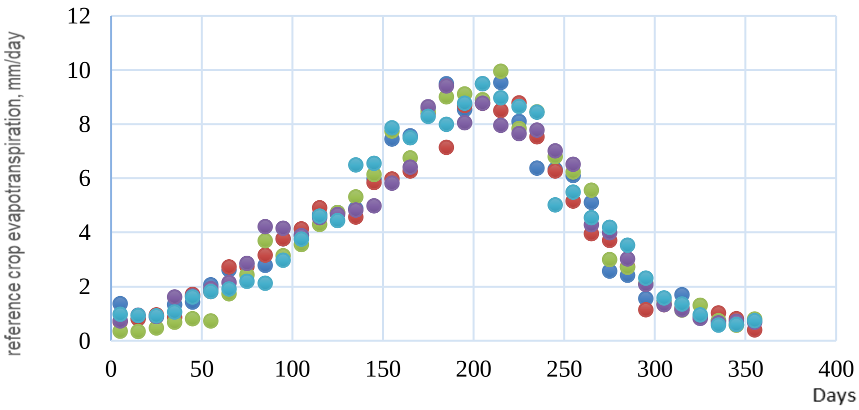
Fig. 1. Locations and altitudes of hydrometeorological stations' locations a.s.l.
Source: compiled by the authors.

Results. In 2015–2019, as a result of studying agro-climatic indicators obtained by 10 hydrometeorological stations of the RA the changing patterns of estimated evapotranspirations per ten days have been identified. The results are shown in the Fig. 2.

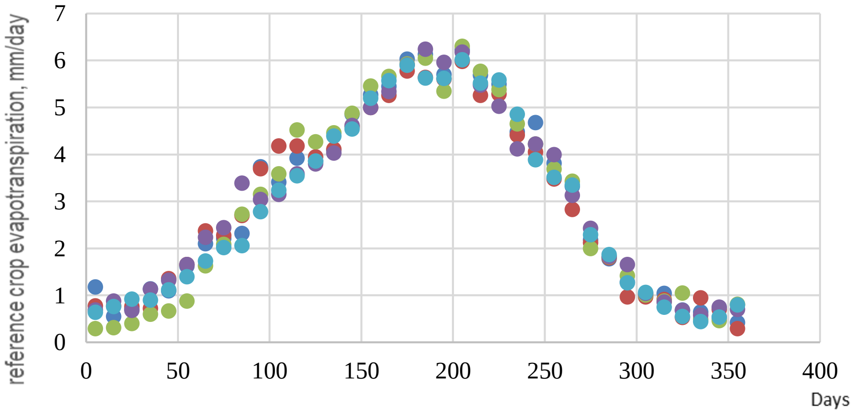
Calculations show that the estimated total evaporation in the lowlands of the Ararat concavity makes 1195.6 *mm*, in the foothill belte – 1308.9 *mm*, and in the mountainous zone – 995 *mm*. The maximum value of evapotranspiration in the foothill belt is mainly due to the wind speed, which is 4–5 times higher than that of recorded in lowlands. Atmospheric precipitations in the lowlands fluctuate in the range of 200–280 *mm*, in the foothills they amount to 430 *mm*, in the mountains – 327 *mm*. Changes in the estimated evapotranspiration and moisture transfer from the sea surface are shown in Fig. 3.



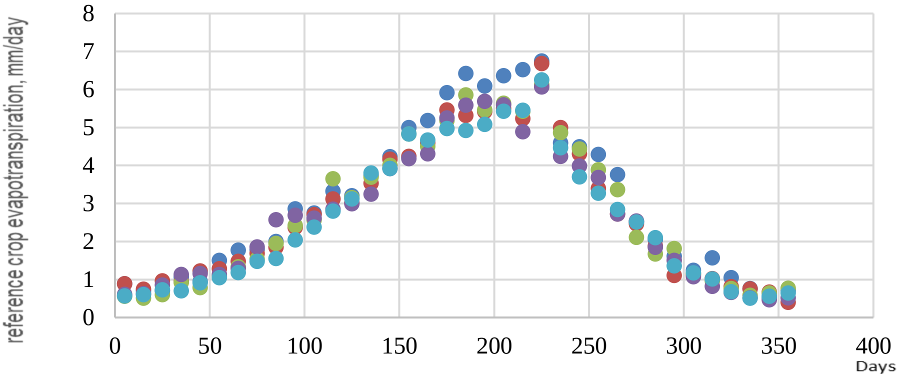
a – Artashat, 829 *m*.



b – Yerevan agro, 942 *m*.

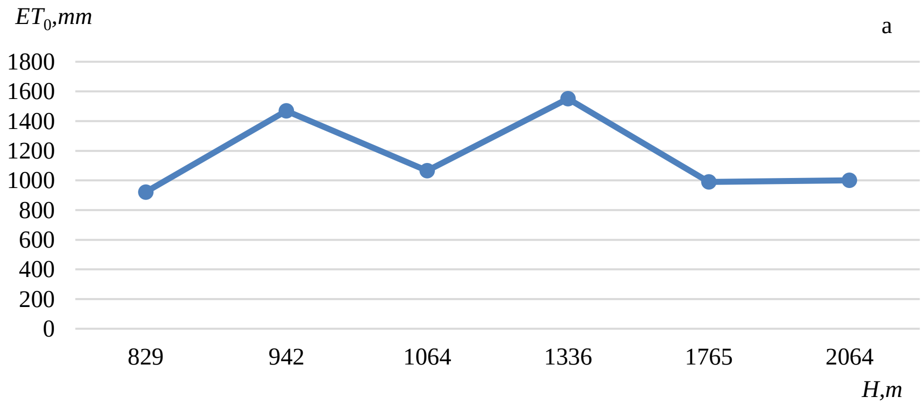


c – Urtsadzor, 1064 *m*.



d – Hrazdan, 1765 *m*.

Fig. 2. Patterns of changes in estimated evaporation amounts for the decades 2015–2019 at hydrometeorological stations of the Republic of Armenia. a) Artashat; b) Yerevan agro; c) Urtsadzor; d) Hrazdan. Source: compiled by the authors.



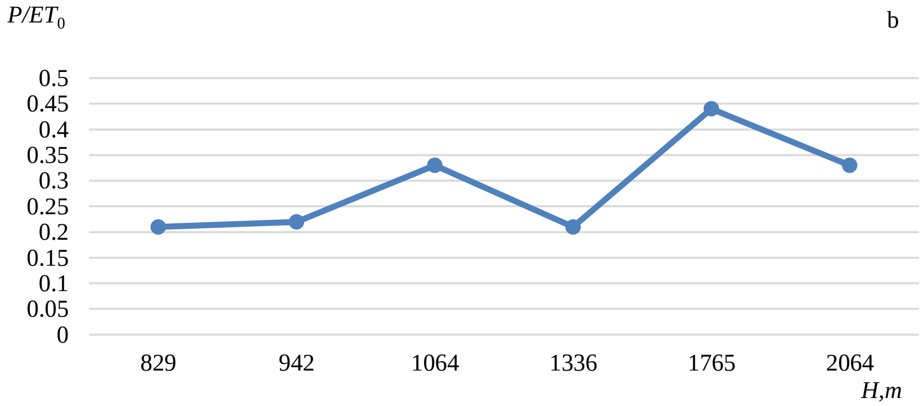


Fig. 3. a) Changes in estimated evapotranspiration; b) changes in moisture transfer.
Source: compiled by the authors.

The dynamics of soil moisture change, depending on the estimated evapotranspiration, is presented in Fig. 4.

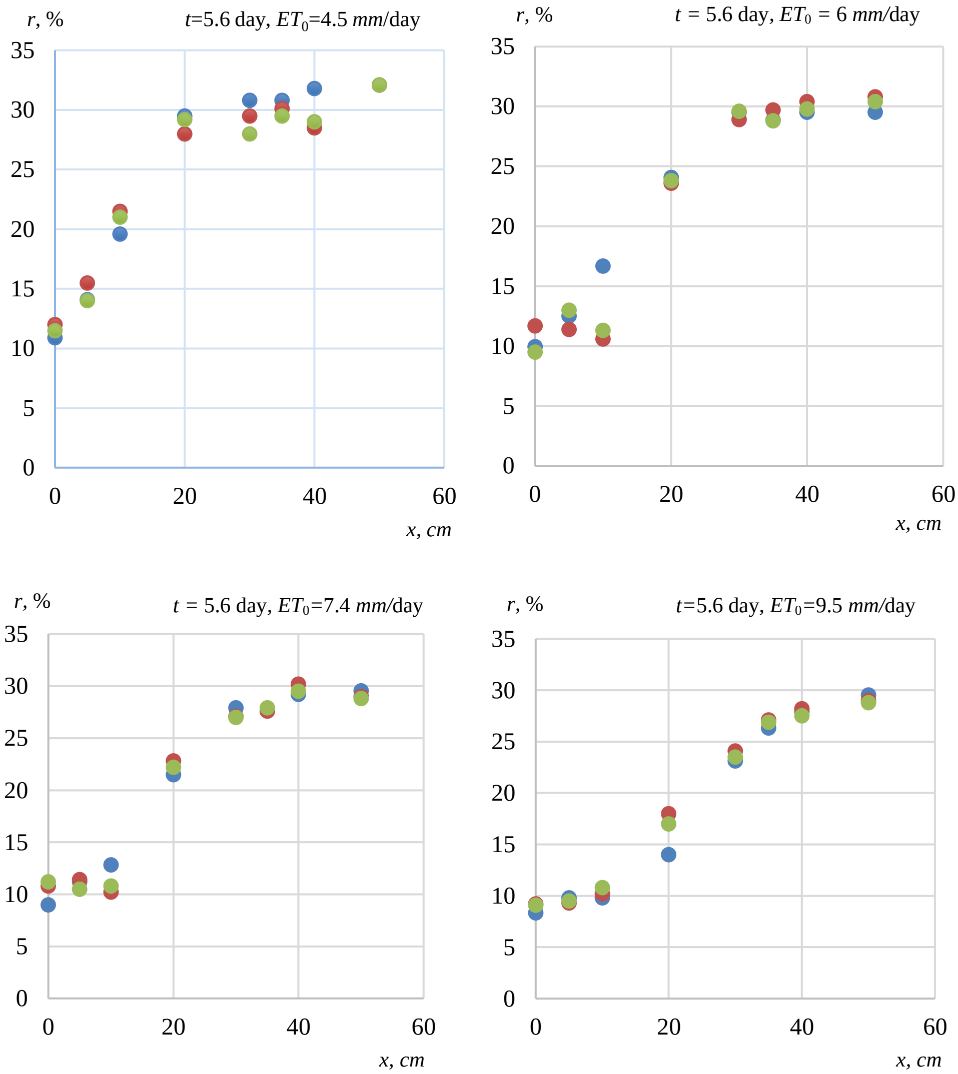


Fig. 4. Dynamics of soil moisture change depending on the estimated evapotranspiration. Source: compiled by the authors.

In the current design model of crops water demand, the soil moisture change per the depth is considered via constant linear law, averaging soil moisture values, which, in its turn, leads to inadmissible errors. The current mathematical model is presented in Fig. 5, a. The studies enable to obtain a new mathematical model, which establishes a relationship between the estimated evapotranspiration rate and the total water evaporation rate from the soil (Fig. 5, b).

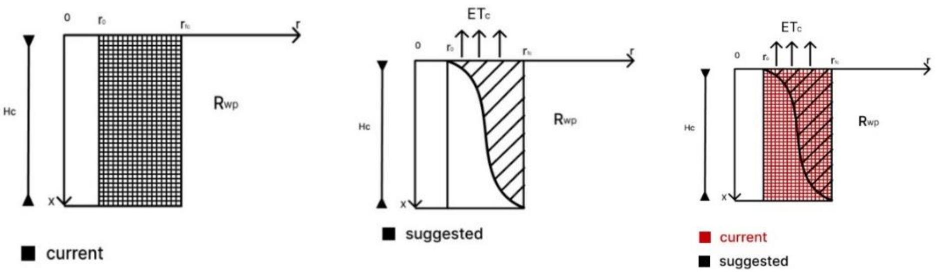


Fig. 5. Calculation of the soil water amount via the current mathematical model (a); the adjusted model (b); current and suggested models for calculating the soil water amount in comparison (c). Source: compiled by the authors.

The dependence between the estimated evapotranspiration rate and the total water evaporation rate from the soil is expressed through Eq. (7):

$$ET_{sc} = ET_0 \frac{\gamma_s}{\gamma_w}\left(1+\frac{\beta_{sh}}{\beta_c}\right)\left(1-\sin\left(\frac{\pi}{2}\cdot\frac{x}{H_c}\right)\right), \quad (7)$$

where ET_0 is the calculated evapotranspiration; γ_s is the soil density; γ_w is the water density; β_{sh} is the area of the plant shadow surface; β_c is the plant nutrition area of; x is the variable depth; H_c is the actively spreading depth ofplant's root system.

If we consider that $ET_{sc} = ET_c \cdot K_c$, then we will get the following dependence for the plant coefficient:

$$K_c = \frac{\gamma_s}{\gamma_w}\left(1+\frac{\beta_{sh}}{\beta_c}\right)\left(1-\sin\left(\frac{\pi}{2}\cdot\frac{x}{H_c}\right)\right). \quad (8)$$

Based on Eq. (8), let's calculate the plant coefficient for potato K_c. The results are presented in Table.

Calculation of the coefficient K_c according to the new mathematical model developed in the result of soil moisture monitoring

ET_0	γ_s/γ_w	ω_{sh}/ω_c	$1+\omega_{sh}/\omega_c$	x	H_c	x/H_c	$ET_c{\cdot}x$	$\sum(ET_c\cdot x)/H_c$	K_c
4	1.25	0.047368	1.047368	5	60	0.083333	16.16876	–	–
4	1.25	0.047368	1.047368	10	60	0.166667	7.676551	–	–
4	1.25	0.047368	1.047368	15	60	0.25	1.999143	–	–
4	1.25	0.047368	1.047368	20	60	0.333333	8.3E–06	–	–
4	1.25	0.047368	1.047368	25	60	0.416667	1.983192		–
4	1.25	0.047368	1.047368	30	60	0.5	7.647075	–	–
4	1.25	0.047368	1.047368	35	60	0.583333	16.13024	–	–
4	1.25	0.047368	1.047368	40	60	0.666667	26.14251	–	–
4	1.25	0.047368	1.047368	45	60	0.75	36.16111	–	–
4	1.25	0.047368	1.047368	50	60	0.833333	44.66235	–	–
							158.5709	3.171419	0.7928

The dynamics of potato coefficient for different development stages is shown in Fig. 6.

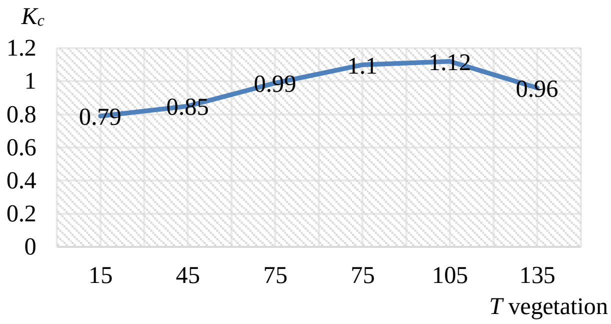


Fig. 6. The change in the values of the K_c coefficient according to the development stage. Source: compiled by the authors.

By means of formula (8) derived on the bases of theoretical and experimental investigations the values of K_c coefficints have been calculated, the numerical designations of which are presented in Table and Fig. 6, which indicate that the developed model enables to receive the numerical value of K_c coefficient at any phase of the crop development and to use it for the determination of various elements for crop irrigation regime.

Discussion. The main goal of estimating evapotranspiration is to identify crops irrigation regimes in different soil and climatic conditions and to this end, currently various calculation methods are widely used in the world practice among which FAO-56 has gained a rather wide recognition [16, 18, 19]. It is also known that in order to retrieve more reliable data, the results of lysimetric examinations are applied, which are coming up just as specific field measurements [4, 5, 11]. Determination of estimated evapotranspiration is based on the energy balance equation [16]. On the bases of water balance equation for the irrigated land areas the optimal water regime of soil-water-plant system is estimated [6, 11, 12]. Various models have been designed and developed in the world practice, which enable to calculate the evapotranspiration depending on the agro-climatic indices [2, 21]. Among the studied models those developed on the bases of climatic factors have practically gained wider application. Anyhow, their results have restricted application [14, 18, 22]. The studies conducted by Sudnitsyn I.I. [24], Penman H.L. [17], Kovalenko P.I., et al. [3] have enabled to evaluate the changing patterns of the soil hydrophysical characteristics depending on the soil mechanical, hydrophysical and chemical properties. The issue of developing a universal model of estimated evapotranspiration is still in the prime focus of multiple researchers' attention and is yet at the development stage [1, 6, 11]. Solution of the mentioned issue would enable to forecast the water regime of irrigated land areas and to use the results for the efficiency increase in the management of irrigated agriculture [6, 8, 10, 11, 13, 20]. Meanwhile, it is also apparent that the evapotranspiration (ET_0) estimated via the Penman-Monteith equation is mainly based on the climatic factors, while the values of crops coefficients (K_c) are calculated based on the average results of field investigations [14, 15]. Upon the model developed by our research group, it is recommended that the crops water demand should be estimated based on the changes of soil moisture dynamics during the vegetation period. In order to design a more universal model, the changing patterns of soil moisture have been analyzed in various evapotranspiration conditions, which enabled to analytically determine the changing domain of crops coefficient per its development phases. Particularly, the numerical calculations enabled to receive the changing domain of K_c for potato per the vegetation period [3, 6, 9, 13]. Unlike the existing diagram, the developed model introduced in the current work considers the plants development rate, soil density, the depth of root system spread. The changing pattern of soil moisture enables to identify the plants water absorption capacity depending also on the soil hydro-physical properties, soil moisture supply coefficient and the maximum water retention capacity.

Conclusion. The conducted studies have revealed the content of a mathematical model for describing evapotranspirations of the plant root system based on the patterns of soil moisture dynamics. It enables to calculate the K_c coefficient of crops, which will contribute to the determination of the required water amount according to the development stages. This approach makes the theory of estimated evapotranspiration practically applicable for different plant species, and enables to determine and plan the irrigation regime of different crops in different soil and climatic conditions. The results of the conducted investigations enable to identify the individual components of crops irrigation regime in the optimal water consumption conditions and to efficiently implement further management of the irrigation procedure.

Received 04.05.2025
Reviewed 04.06.2025
Accepted 15.08.2025

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ՀՀ-ՈՒՄ ՈՌՈԳՎՈՂ ՀՈՂԵՐԻ ԳՈԼՈՐՇԻԱՑՄԱՆ ԵՎ ԽՈՆԱՎՈՒԹՅԱՆ ԴԻՆԱՄԻԿԱՆ

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Հետազոտությունները վերաբերում են տարբեր գյուղատնտեսական գոտիների ոռոգվող պայմաններում մշակվող մշակաբույսերի ընդհանուր ջրի պահանջարկի գնահատման մեթոդների մշակմանը: Որպես բազային տվյալներ ծառայել են 2015–2019 թվականներին 10 հիդրոօդերևութաբանական կայանների կողմից գրանցված ագրոկլիմայական ցուցանիշները: CropWAT ծրագրի միջոցով հաշվարկվել է մշակաբույսերի առավելագույն ջրի պահանջարկը տասնամյակների ընթացքում: Հողի խոնավության մոնիթորինգի արդյունքները հնարավորություն են տալիս բացահայտել տարբեր գոլորշիացումների ազդեցությունը հողի խոնավության դինամիկայի վրա: Բացահայտվել է մշակաբույսերի ընդհանուր գոլորշիացման արագության փոփոխության պատկերը հողի խորության տարբեր արժեքներում, իսկ փորձարարական արդյունքների մաթեմատիկական մշակման հիման վրա ստացվել է հաշվար-կային բանաձև, որը հնարավորություն է տալիս լուծել մշակաբույսերի գործակցի հաշվարկման խնդիրը ոչ ստանդարտ պայմաններում: Հողի խոնավության փոփոխության հայտնաբերման նոր մաթեմատիկական մոդելն ավելի ճշգրիտ է պատկերում հողի խոնավության ռեժիմը, ինչը հնարավո-րություն է տալիս ավելի ճշգրիտ նկարագրել հողից և բույսերի մակերեսներից ընդհանուր գոլորշիացման դինամիկան ոռոգման միջակայքերի ժամանակա-հատվածում:

Г. М. ЕГИАЗАРЯН, Р. А. ДАНИЕЛЯН

ДИНАМИКА РАСЧЕТНОГО ИСПАРЕНИЯ И ВЛАЖНОСТИ ОРОШАЕМЫХ ПОЧВ АРМЕНИИ

Резюме

Исследования связаны с разработкой методов оценки общей потребности в воде сельскохозяйственных культур, возделываемых в условиях орошения различных сельскохозяйственных зон. Исходными данными послужили агроклиматические показатели, зафиксированные в 2015–2019 гг. на 10 гидрометеорологических станциях. С помощью программного обеспечения CropWAT рассчитана максимальная потребность сельскохозяйственных культур по декадам. Результаты мониторинга влажности почвы позволяют раскрыть влияние различных суммарных испарений на динамику влажности почвы. Раскрыт характер изменения скорости суммарного испарения сельскохозяйственных культур при различных значениях глубины почвы, а на основе математической обработки результатов эксперимента выведена расчетная формула, позволяющая решить задачу расчета коэффициента влажности сельскохозяйственных культур в нестандартных условиях. Новая математическая модель определения изменения влажности почвы более точно отображает режим влажности почвы, что позволяет точнее описать динамику суммарного испарения с поверхности почвы и растений за период межполивных промежутков.