Estimating the Amount of Water Required for Crop Irrigation Based on the Application of FAO's CROPWAT Program in the Case of Kashkadarya Region

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Abstract. The article calculates the amount of water required for irrigation in the irrigated areas of Kashkadarya region based on the climate change conditions using the cropwat program of FAO. The standard evapotranspiration was calculated taking into account the climate data and the stable factors of the plant and weather conditions. In CLIMWAT 2.0, the climate indicators are monthly averages of effective precipitation based on multiyear data from the USDA Soil Conservation Service of the United States Department of Agriculture. Service) calculated as follows using the formula. The water demand of the agricultural crops grown in the experimental plots was calculated. The granulometric composition of soil samples was determined using the soil structure triangle (also known as the Ferret triangle) developed by the US Department of Agriculture (USDA). Using the CROPWAT program, irrigation rates, number of irrigations and total irrigation rates were calculated for the cotton crop placed in the research facility. Based on the application of the FAO UN CROPWAT program, the one-time irrigation standards for the cotton crop are 700-930 m3/ha, the number of irrigations is 7 times and the seasonal irrigation standard is 6400 m^3/ha, in the usual way, that is, when calculated on the basis of II-hydromodule regional indicators, the one-time irrigation standards are 700-930 m^3/ha, the number of irrigations is 9 times, and the seasonal irrigation standard is 7100 m^3/ha and the indicators were close to each other. This indicates that the calculations are done correctly.

Keywords: CROPWAT, CLIMWAT, irrigation, cotton, Granulometric content, field moisture capacity, soil water characteristics, crop coefficient.

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1 Introduction

Current research on assessing crop water productivity and optimizing agricultural water allocation primarily focuses on three approaches: optimizing regional planting areas using traditional mathematical algorithms, developing spatial distribution models for crop optimization, and simulating optimization through agent or dynamic systems [1-2]. However, a significant limitation of most studies lies in their focus on static optimization, neglecting the dynamic nature of water availability and crop demands.

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Drip irrigation is the most economical and effective method of irrigating crops in agriculture. Based on crop monitoring in the regions of the Republic of Uzbekistan, it can be observed that in the Kashkadarya region, the majority of crops are grain crops, vegetables, and cotton [3-4]. Many problems are encountered in the irrigation of these crops (Fig. 1). Water resources are a problem for Kashkadarya region, mainly in the desert areas, and based on it, the discussion of irrigation methods and regime increases. We can see the possibility of managing the planned and expected yield for the crop based on irrigation [5-7]. For example: Through drip irrigation, economic efficiency can be increased by delivering water and nutrients to the root part of the crop instead of to the ground [8-10]. In the decision of the President of the Republic of Uzbekistan No. PQ-2, dated November 10, 2021, titled "On Measures to Improve the System of Financing the Production of Raw Cotton and Its Harvesting Costs," it was established that, starting from the 2022 harvest, the production of raw cotton and preferential financing of cotton harvesting will be carried out through cotton-textile clusters and elite seed farms within the Seed Development Center, funded by the State Support Fund for Jalygina. Currently, monitoring of crop greenness is being conducted using modern GIS technologies, depending on the location of the crops [11-13].

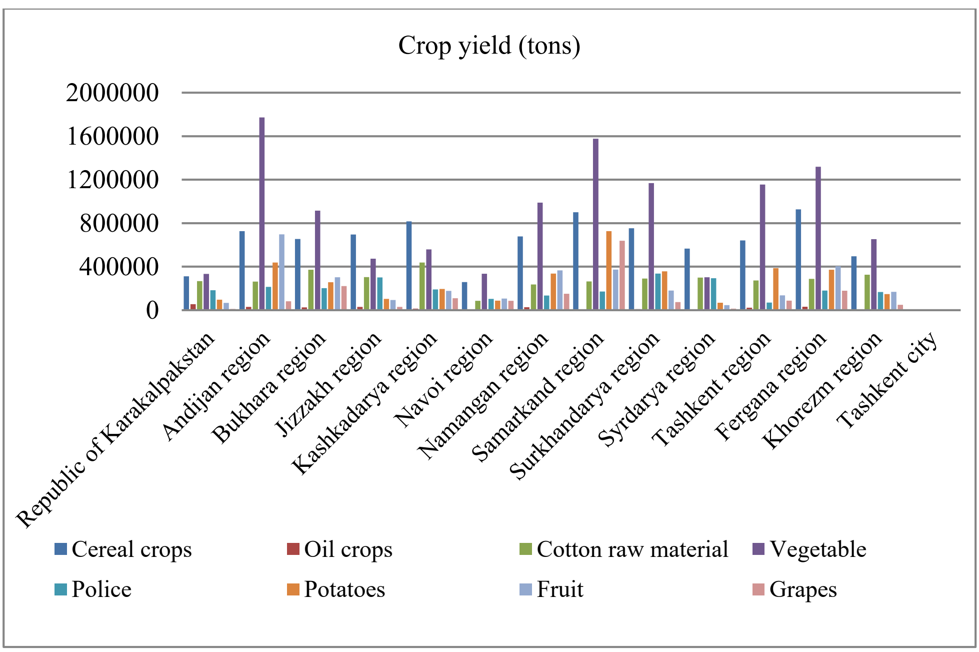

Fig. 1. Crop yield data of Uzbekistan.

The reason is that due to this technology, the consumption of water is reduced by 5 times, the cost of mineral fertilizers and technical works is reduced by 2 times, and the productivity has also been proven to increase [14-15]. Therefore, this method of watering is becoming more popular every year. Irrigation periods of cotton are determined depending on soil moisture, physiological indicators of leaves, external signs of plants and flowering joints. Determining the irrigation period based on soil moisture is the most objective method. For this, soil samples are taken from every 10 cm layer to the depth of the calculated layer with the help of a soil drill and their moisture content is determined. If the soil moisture is 65-70% compared to the limited field moisture capacity (CHDNS), irrigation is carried out [14,16].

The Penman-Monteith-FAO method has been established as the international standard for determining and quantifying reference crop evapotranspiration (ETo). Numerous studies have investigated the spatial distribution of ETo using this method, comparing its outputs with measured ETo values [17]. In field conditions, the duration of watering is determined as follows: if the soil taken from a depth of 30-40 cm does not become compacted when squeezed by hand, and it scatters when slowly thrown on the ground, then watering is necessary. The duration of watering can also be determined by the morphological signs of the leaf. If the color of the leaves has changed to dark green, when the turgor condition in the leaves decreases, at 14:00-15:00 in the afternoon, if the main vein of the leaf does not crack when it bends, it is necessary to water the cotton. For this purpose, at least 30-40 plants are selected from each hectare along the diagonal of the plot. Irrigation rates should be stratified depending on soil conditions [18]. The rate of irrigation in thick sand and loam soils is around 1100-1200 m3/ha. At this rate, the root layer of the soil is very well moistened and watering can be done every 14-16 days [19-21]. Cotton irrigation criteria is a matter of determining the amount of water needed to irrigate the cotton plant at an optimal level. This is important because overwatering can damage the soil, reduce yields, and waste water resources [22-23]. The amount of watering cotton should be optimal, that is, to fully satisfy the plant's need for water, but not to damage the soil. Many factors must be taken into account when determining the amount of cotton to irrigate, including the stage of plant development, soil characteristics, climatic conditions, irrigation methods, and the type of cotton.

2 Method

The CLIMWAT 2.0 program (Munoz and Griezer (2006)) and the average monthly climate data of the closest weather station to the experimental sites are used. As part of the research, the average monthly climate data of the "Samarkand" weather station, located in the area closer to the experimental sites, was used. Calculations were performed on the basis of first input of climate data into the CROPWAT program.

3 Result and Discussions

It is known that the amount of water used to cover evapotranspiration from the cultivated area is determined by the plant's water demand. Plant evapotranspiration under standard conditions (a healthy, well-fertilized, large-area crop with optimal soil moisture and potential yield) and plant water requirements are the same. In the first case, it refers to the water consumed by the plant through evapotranspiration, and in the second case, it means the amount of water that should be given for irrigation.

Plant evapotranspiration is determined by the Penman-Monteith method (Allen R. et al., 1998) using the following formula, taking into account climate data, direct integration of plant stability factors, albedo and air resistance:

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

where, ETo - standard evapotranspiration [mm/day];
R_n - net radiation from the plant surface [MDj/m^2/day];
G - heat flux density in soil [MDj/m^2/day];
T - average daily air temperature at a height of 2 m [°C];
u_2 - wind speed at a height of 2 m [m/s];
e_s - saturated vapor pressure [kPa];
e_a - pure vapor pressure [kPa];
e_s - e_a - saturation vapor pressure deficiency [kPa];
Δ - pressure curve slope [kPa/°C];
γ - psychrometric constant [kPa/°C].

Etalon evapotranspiration (ETo) is a standard indicator that allows comparison of evapotranspiration calculated in different seasons of the year and can be used for different crops.

When calculating the equation [1], it is necessary to collect minimum data such as standard climatic indicators of the area - solar radiation (sunshine time), air temperature and humidity, wind speed. To do this, in the open space of the selected area, it is possible to install a mini meteostancy, which can be recorded by itself at a height of 2 m. In this case, the area where the mini meteostancy will be installed should have a green lawn, should not obstruct the direction of the wind and should not be shaded.

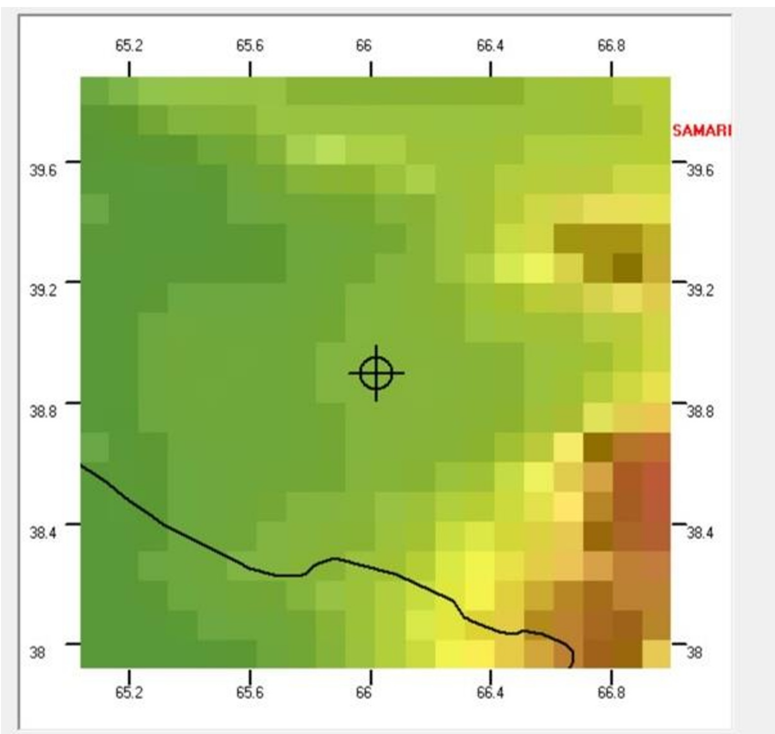

Fig. 1. "Samarkand" meteostancy location in CLIMWAT 2.0 program.

But in many cases, we face economic and organizational problems, such as the cost of installing such mini weather stations, the cost of hiring a permanent worker for maintenance. With this in mind, the computational data is obtained from the data of the chief Hydrometeorological-owned station of Uzbekistan, closest to the experimental field, and from the data of the CLIMVAT 2.0 program (Munoz and Grizer 2006), created specifically for the FAO's CROPVAT program.

As part of the research work, the average monthly climate data of the "Samarkand" meteostancy, located in the area closer to the experimental plots, was used. Calculations were performed on the basis of prior input of climate data into the CROPWAT program.

The data of the weather station "Samarkand" was obtained and the geoFigureic location of the meteostancy was displayed using the CLIMWAT 2.0 program. Figure 1.
The coordinate grid is given in degrees, with north latitude on the vertical and east longitude on the horizontal. In the CLIMWAT 2.0 program, climate indicators are given in the form of monthly averages based on multi-year data (Table 1).

Table 1. Average monthly climate data for the weather station "Samarkand" obtained from the CLIMWAT 2.0 program (columns 2-8 are taken from SAMARQAND.pen and columns 9-10 are summarized from SAMARQAND.cli files).

Months	T_{max} [°C]	T_{min} [°C]	Air humidity [%]	Wind speed [km day^{-1}]	It's time for the sun to shine [hour]
1	2	3	4	5	6
January	5.9	-2.9	76.0	311.0	4.0
February	7.9	1.8	74.0	337.0	4.6
March	13.1	3.1	71.0	354.2	5.3
April	21.1	9.3	62.0	354.2	7.6
May	26.0	12.9	55.0	337.0	10.0
June	32.9	18.3	46.0	337.0	11.0
July	31.9	16.9	42.0	319.7	12.3
August	34.0	18.5	41.0	293.8	12.8
September	28.0	12.0	47.0	267.8	10.2
October	21.3	6.5	59.0	259.2	7.7
November	15.0	2.6	67.0	293.8	5.4
December	9.4	-0.3	73.0	293.8	3.9

Continuation of table 1.

Months	Solar radiation [MJm^{-2}day^{-1}]	Evapotra. ETo [mm]	Amount of precipitation [mm]	Amount of effective precipitation [mm]
1	7	8	9	10
January	7.14	0.85	46.3	42.9
February	9.76	1.15	44.4	41.25
March	13.28	1.93	68.0	60.6
April	18.85	3.58	57.6	52.29
May	23.93	5.26	40.2	37.61
June	25.9	7.2	5.8	5.75
July	27.82	7.3	3.5	5.75
August	28.1	7.6	0.6	0.6
September	20.23	4.84	3.6	3.58
October	13.93	2.73	21.4	20.67
November	8.89	1.61	27.0	25.83
December	6.44	1.02	41.9	39.09

The effective precipitation in Table 1 was calculated using the USDA Soil Conservation Service formula:

$$Pre_{effec} = 125 / 3 + 0.1 * Pre_{deca} \qquad Pre_{month} > 250 \text{ mm} \tag{2}$$

Here, $Pre_{effective}$, $Pre_{decadal}$, Pre_{month} is the sum of effective, ten-day and monthly rainfall respectively.

The standard evapotranspiration (ET_o) calculated on the basis of the above analyzes and climate data was used to calculate the water demand of crops based on the FAO program. It should be noted that there are a number of shortcomings in the data on different crops (type of crops, variety, physiological parameters, etc. vary by region), the Penman-Monteith method is used to determine the reference evapotranspiration (ETo). The ETs/ETo ratio, called the crop coefficient (Ks), which is accepted based on research, shows the relationship between ETs and ETo and is used to determine crop evapotranspiration (ETs):

$$ET_c = K_c * ET_o \tag{3}$$

Growth period, crop coefficient (Ks), maximum root depth, crop height, yield loss coefficient due to moisture deficiency of cotton planted in the experimental plots of Karshi and Qamashi districts based on FAO 56 Irrigation and drainage data (Allen et al., 1998) and the conditions of the area, plant were calculated based on physiology and available literature materials, and their results are shown in Tables 2 and 3.

Table 2. Selected indicators for the FAO program for cotton planted in the field in 2022.

Field area	Crop type	Planting years	Growth period		max. root depth
			planting	collection	[m]
Karshi	cotton	2012	14 April	2 October	0.7-1.5 (1.2)

Note: The period of cotton harvest is given conditionally, and it was taken according to the third harvest (end) period under field conditions).

Table 3. Periods of the growing season by phases, crop coefficient (*Ks*), fraction of soil moisture reduction (p) and yield loss coefficient due to its lack (*Ks*) for crops planted in experimental plots.

Crop type	A) Growth phase and *Ks*			
	I	II	III	IV
cotton	30/0.35	50/0.35-1.2	55/1.2	45/0.6
Crop type	B) p and *Ks* corresponding to the growth phase			
	I	II	III	IV
cotton	0.65/0.2	0.65/0.5	0.65/0.45	0.65/0.25

Note: In the photo - A) days of the growth phase, B) soil moisture reduction fraction (p); In the denominator – A) crop coefficient (Ks); B) yield loss coefficient (Ks).

It is known that the efficiency of water absorption by plants in field conditions depends on the type of soil, because depending on the characteristics of the soil, the moisture capacity of the soil, the rate of water absorption into the soil, the depth of plant root growth, etc. determine the volume, duration and number of water. The granulometric composition of the soil samples was determined using the soil structure triangle (also known as the Ferret triangle) developed by the US Department of Agriculture (USDA) Figure 3.
Soil water characteristics (moisture capacity, water permeability, etc.) were calculated using the program Hydraulic Properties Calculator, NRS (Sakston K., 1986) (Fig. 4).

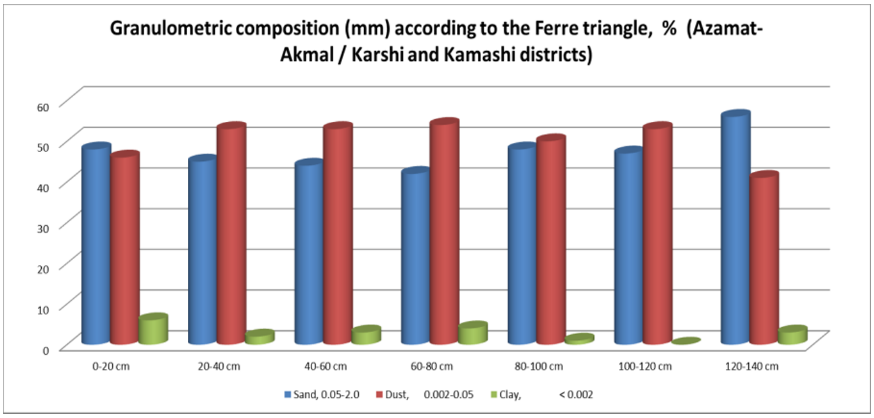

Fig. 2. Granulometric composition (mm) according to the Ferre triangle, % (Azamat-Akmal/Karshi and Kamashi districts).

In addition to the sand and clay fraction, the organic sediment of the soil, salinity content, presence of gravel, degree of hardness and moisture indicators can also be included in the program. In this case, with the help of the program, a more accurate calculation of the water properties of the soil is achieved. Based on field soil samples, each site was characterized according to the FAO program (only one soil horizon is included in the program, so the sample results obtained by depth are averaged over depth) (Table 4).

The percentage of initial total plant absorbable moisture loss (TAM = field moisture capacity, FS - lower limit of moisture, WP) was taken as 5 %.

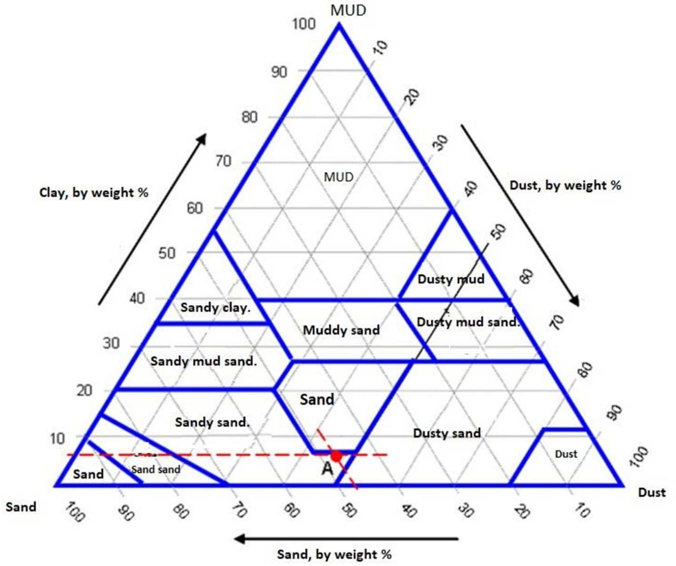

Fig. 3. USDA classification of soil by granulometric composition (Hillel D, 2004): clay (<0.002 mm), dust (0.002-0.05 mm) and sand (0.05-2 mm).

Note: Soil names and the third granulometric composition are obtained from the intersection of a parallel straight line drawn by the percentages of at least two granulometric compositions, for example, Sand - 48% and Clay - 6% (red line intersection, A), soil name: sandy loam and by granulometric content: dust – 46%.

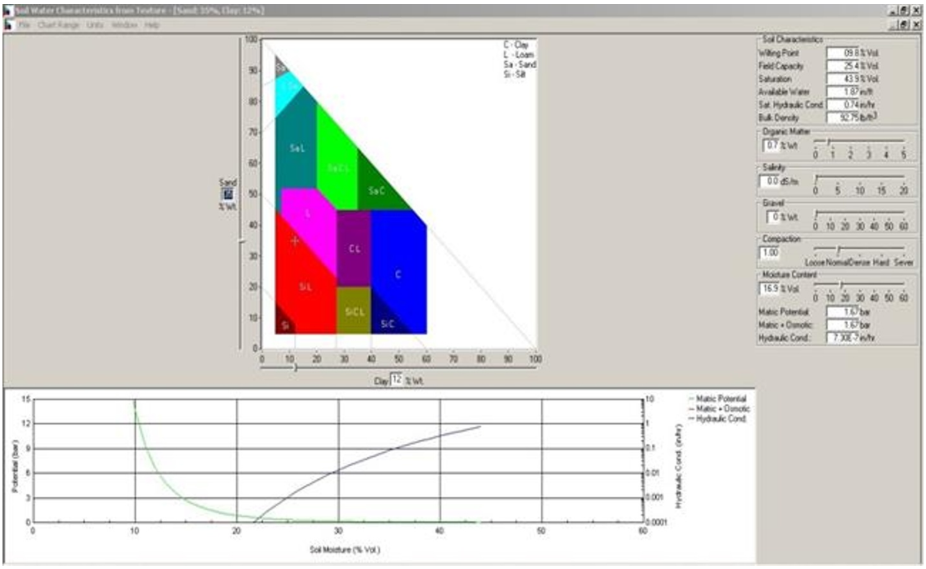

Fig. 4. Soil water characteristics in the program Hydraulic Properties Calculator NRS (Saxton K., 1986).

Note: Soil water properties are shown in the upper right corner of the frame (lower moisture limit, moisture capacity, upper moisture limit, required moisture, saturated hydraulic resistance, and bulk density) Saxton K. (1986) method, the three soil textures described by the USDA (sand, clay, and silt, in percent by weight), only the sand and silt contents are included in the NRS.

Using the CROPWAT program, based on the data of the calculations performed within the study, the irrigation rates, the number of irrigations, and the total irrigation rates were calculated for the cotton crop placed in the research facility (Table 5).

Based on the above information, irrigation rates, number of irrigations and total irrigation rates were calculated for agricultural crops placed in the research facilities using the CROPWAT program (Table 5).

Table 4. Characterization of soil samples in accordance with the FAO program and soil hydraulic parameters for the soil section (Saxton K.E., 1986).

Field name	Soil depth, cm	Physical clay	Name of soil*	Granulometric composition (mm) according to the Ferre triangle, %		
				Sand, 0.05-2.0	Dust, 0.002-0.05	Clay, < 0.002
1	2	3	4	5	6	7
Azamat-Akmal / Karshi and Kamashi districts	0-20	13.3	Sand	48	46	6
	20-40	3.6	Porous sand	45	53	2
	40-60	4.7	Porous sand	44	53	3
	60-80	5.5	Sticky sand	42	54	4
	80-100	4.1	Porous sand	48	50	1
	100-120	1.6	Porous sand	47	53	0
	120-140	9.3	Sticky sand	56	41	3
Average	**0-140 cm**	**6.0**		**47**	**50**	**3**

Continuation of table 4.

Name according to FAO		Field wet capacity (FC), %	Lower humidity limit (WP), %	Max. absorption rate (V), cm/hour	Soil moisture absorbed by the plant (FC-WP), mm/m	Max. absorption rate (V), mm/day
8	9	10	11	12	13	14
SL	Sandy Loam	35.8	12.9	99.3	229.0	41.4
ZL	Silt Loam	37.1	13.0	120.3	241.0	50.1
ZL	Silt Loam	36.0	12.6	105.7	234.0	44.0
ZL	Silt Loam	36.6	12.7	111.2	239.0	46.3
ZL	Silt Loam	34.9	12.4	95.6	225.0	39.8
ZL	Silt Loam	34.5	12.5	84.9	220.0	35.4
SL	Sandy Loam	32.4	11.8	76.2	206.0	31.8
ZL	**Silt Loam**	**35.3**	**12.6**	**99.0**	**227.7**	**41.3**

Note: Columns 10-12 were calculated in the NRS program and depth averaged for the FAO program.

Table 5. Irrigation norms of crops in research facilities (calculated using CROPWAT software).

Field name	Crop type	Irrigation norm, m^3/ha	Number of waterings	Seasonal watering norm m^3/ha
Karshi and Kamashi	Cotton	700-930	7	6400

According to the current regulations in the regions where the research objects are located, the planning of irrigation for agricultural crops—such as the irrigation norms, irrigation periods, number of irrigations, and seasonal irrigation norms—are determined based on the indicators of the II-hydromodule region (Table 6).

Table 6. Crop irrigation norms in the research object
(based on the current hydromodule zoning for II - hydromodule region).

Field name	Crop type	Irrigation norm, m^3/ha	Number of waterings	Seasonal watering norm m^3/ha
Karshi and Kamashi	Cotton	700-900	9	7100

As a primary result of the study, it should be noted that the calculation of agricultural crop irrigation rates based on FAOs CROPWAT program increased the accuracy of setting irrigation rates.

4 Conclusion

The results demonstrate the ability of the model to provide valuable information on water demand for different crops under different climatic conditions. In particular, the sensitivity of the model to crop-specific parameters such as evapotranspiration rate and water use efficiency highlights the importance of accurate input data for reliable irrigation water assessment. The analysis revealed spatial variations in water demand across the region, highlighting the need for specific irrigation management practices. This study highlights the important role of integrated water management strategies, including optimized irrigation schedules, efficient water delivery systems and water conservation measures, to ensure sustainable water use in Kashkadarya region. This study will serve as a basis for water resource awareness in the region. Further studies incorporating factors such as soil moisture dynamics, drainage characteristics and economic aspects are recommended to clarify irrigation water requirements and optimize water allocation to improve agricultural efficiency while conserving water resources. As can be seen from the results, the number of irrigation applications and the amount of water classified for irrigation are clearly defined.

Using the FAO UN CROPWAT program, the irrigation rates, the number of irrigations and the total irrigation rates for cotton crops located in the research object were calculated. Based on the application of the FAO UN CROPWAT program, the one-time irrigation rates for cotton crops are 700-930 m^3 / ha, the number of irrigations is 7 times, and the seasonal irrigation rate is 6400 m^3 / ha. in the usual way, that is, when calculating on the basis of regional indicators of the II-hydromodule, the one-time irrigation rates are 700-930 m^3 / ha, the number of irrigations is 9 times, and the seasonal irrigation rate is 7100 m^3 / ha and the indicators were close to each other. This indicates that the calculations are correct. Calculating irrigation rates for agricultural crops based on the FAO CROPWAT program has increased the accuracy of setting irrigation rates.

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