Optimization Of The Irrigation Of Agricultural Crops Regime On Sod-Podzolic Soils Of Watershed Areas Of The Non-Chernozem Zone Of The Russian Federation

Victor Vladimirovich PCHELKIN[1♣] , Yuri Ivanovich SUKHAREV[1] , AleksandrEvgenievich KASIANOV[1] , OlegViktorovich KABLUKOV[1] , Kristina Sergeevna SEMENOVA[1]

[1]Russian State Agrarian University - Moscow Timiryazev Agricultural Academy, Institute of land Amelioration, water management and construction, Department of land Reclamation and Recultivation, Moscow, 127550, Russian Federation

Abstract: The studies carried out in lysimeters and at the experimental site in 2010–2017 formed the basis for the development of an irrigation regime for agricultural crops. When conducting scientific research on the water regime of sod-podzolic soils during irrigation of agricultural crops, the technique developed at the Department of Land Reclamation and Reclamation of the Russian State Agricultural University — Moscow Timiryazev Agricultural Academy. Formula for calculating water consumption for research conditions has been obtained. Empirical coefficients for this equation are established, depending on the natural climatic zone and soils. The biological coefficients for beetroot, oat and vetch mixture, potatoes, carrots and coefficients that consider the decrease in soil moisture from the optimal values for these crops have been determined. A formula for calculating water consumption for the conditions of research has been obtained. The optimal limits of moisture content of sod-podzolic soil of watersheds are revealed. A relationship has been established between the calculated depths and numbers of decades from the beginning of the growing season of plants. The irrigation regime calculated according to the modernized model of A.I. Golovanov, for research conditions. A graph of the relationship between the actual values of irrigation norms (M_f) and the calculated ones (M_r) is presented. A comparative analysis was carried out, which showed that the irrigation norms obtained during the development and substantiation of the irrigation regime of the studied crops (Table 5) are not contradictory in comparison with the irrigation norms recommended by other authors (Table 6).

Key words: water; irrigation regime; sod-podzolic soil; total water consumption; beetroot; oat and vetch mixture; potatoes; carrot (Daucus Carota L.)

1 INTRODUCTION

Irrigation in the center of the Non-Chernozem Zone of Russia complements soil moistening with natural precipitation. It provides stabilization and intensification of agricultural production. For the conditions of

[1]Russian State Agrarian University - Moscow Timiryazev Agricultural Academy, Institute of land Amelioration, water management and construction, Department of land Reclamation and Recultivation, Moscow, 127550, Russian Federation

♣ Corresponding author, e-mail: 9766793@mail.ru

natural moisture deficit, Russian scientists have proposed various methods for calculating the irrigation regime of agricultural crops. A. Alpatiev (Alpatiev, 1954; Alpatiev, Ostapchik, 1971) used bioclimatic coefficients, Budyko M.I. (Budyko, 1956) - components of the radiation balance, Vaneyan S.S. (Vanyan, Menshikh, 2010) - the average air temperature, Golovanov A.I. (Golovanov, 1993) - deficiency of air humidity, Danilchenko N.V. (Danilchenko, 1982), Dubenok N.N. (Dubenok, 1984) - meteorological indicators, Kostyakov A. (Kostyakov, 1960) - coefficient of water consumption, Maslov B.S. (Maslov, 1974) and others. Abroad, water consumption of agricultural crops was associated with empirical coefficients with meteorological indicators by the following researchers: Awady, MN, Vis, EG, Kumar, R., Mitra, S. (Awady et al., 2003), Badr AE .; Bakeer G.A .; El-Tantawi M.T. and A.H. Awwad (Badr et al., 2006), Christiansen, J.E. (Christiansen, 1942), FAO (FAO, 1985), Hagan R. M., Haise H. R., Edminster T. W. (Eds) (Hagan et al., 1987), Heerman, D. F.; Martin, D. L.; Jackson, R.D. and E.K. Sleghman (Heerman et al. 1990), NastaranBasiriJahromi, Amy Fulcher, Forbes Walker, and James Altland. (Nastaran et al., 2020), Barker JB, Franz TE, Heeren DM, Neale CMU, Luck JD (Barker et al., 2017), Steven R. Evett, Kenneth C. Stone, Robert C. Schwartz, Susan A. O'Shaughnessy, Paul D. Colaizzi, Scott C. (Evette et al., 2019). Recommended calculation methods based on empirical coefficients are advisable to apply for natural and climatic conditions in which field experiments were carried out. Therefore, in order to fully take into account the process of water consumption and moisture exchange in the calculated layer of soddy-podzolic soils of the watersheds and to clarify the ranges of moisture regulation, were carried out in 2010–2015. experimental studies of the irrigation regime of agricultural crops at the experimental site of the Institute of Melioration, Water Management and Construction named after A.N. Kostyakova, Russian State Agrarian University - Moscow Agricultural Academy named after Timiryazev, located in the Moscow region.

Formula for calculation of crop water consumption for the considered conditions was obtained. Empirical coefficients for this equation depending on natural-climatic zone and soils were established. Biological coefficients were determined for red beet, oat and vetch mixture, potato, garden carrot and coefficients taking into account decrease of soil moisture from optimal values for these crops.

The optimum moisture limits of sod-podzolic soil in watersheds were revealed. Correlation between calculated depths and decade numbers from the beginning of plant vegetation is established. The irrigation regime calculated by the modernized model of Golovanov for research conditions is presented.The purpose of the given research is the development of crop irrigation regime on the sod-podzolic soils of the watershed territories of the non-black soil zone of Russia.

2 MATERIALS AND METHODS

The territory of the southern taiga subzone of the non-black soil zone of Russia covers an area of 2.45 million square kilometers and is divided into two provinces such as the Baltic and Mid-Russian. Land resources of the Mid-Russian province, where the research was conducted, include 9 million hectares of arable land and 85% of them are located on the sod-podzol soils. Among them, 30% of soils are formed in the watershed areas.

1. Climate and soils

The Mid-Russian province belongs to the temperate mid-continental belt with mild winters in the west and moderately cool summers in the east. The sum of biologically active air temperatures ranges from 1600 to 2200°C and the duration of the vegetation period is 110-140 days. The amount of atmospheric precipitation per year is 525-650 mm. In some summer months there are dry periods lasting from 4-6 to 10-30 days, which causes a deficit of moisture in the soil.

In the Mid-Russian province, sod-podzolic soils of different degrees of podzolization and thickness of the sod layer prevail. A map of the central part of the non-black soil zone of Russia is shown on Fig. 1.

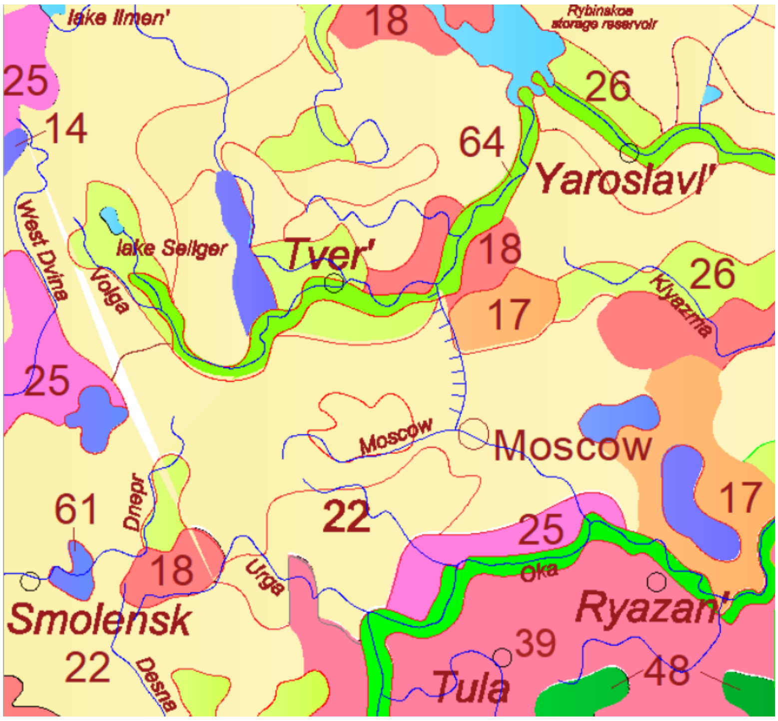


Fig. 1. A map of the central part of the non-black-soil zone of Russia

Source: http://ezetek.ru/docs/faq/rf-map.jpg;

Soils of taiga and forests:

14 - textural-podzolicilluvial-gleyey;

17 - illuvial-humus podzols;

18 - illuvial-humus gleyeypodzols;

22 - sod-podzolic lingual;

25 - sod-podzolicgleyey.

Forest-steppe and steppe soils: 39 - gray; 48 - cryptogleychernozems including solonetzic soils.

Soils of bogs and river floodplains: 61 - peaty-oligotrophic; 64 - alluvial light humus soils.

Sod-podzolic soils contain 0.8-2% of humus, their acidity is 4.0-5.5, saturation with bases is up to 80%. They are poor in nitrogen, phosphorus, and calcium. Biological activity of uncultivated sod-podzolic soils is low. Significant areas of natural forage lands and arable land in the northwestern and northeastern regions are littered with stones. Soils of the non-black soil zone by their granulometric composition are represented by loams, sandy loam and sandy soils. Variation of density of natural soil texture by area and depth is 1.37...1.80 g/cm^3. Density of arable horizon of soil is less and lower horizons are higher. Density of the solid phase of soil varies by depth in the range from 2.40 to 2.70 g/cm^3.The change in soil porosity is 0.43...0.35 as a fraction of volume (cm^3/cm^3). Values of absolute moisture capacity (AMC) are 0.40 to 0.31 in fractions of volume. Variations of the ultimate field moisture capacity (UFMC) are 0.37...0.25 in fractions of volume (cm^3/cm^3). Maximum moisture permeability varies little along the profile and varies from 0.055 to 0.04 in fractions of volume. Water permeability of the pilot plot is low; the filtration coefficient (Fc) in the upper arable horizon is 0.23 m/day, and in the deeper illuvial horizon (80 cm) - 0.42 m/day.

The variation of humus content is from 1.08 to 3.69 % and the average for the experimental plot is 2.34 %. Soil acidity was 6.6-7.7. Content of nitrate nitrogen (NO3) was 19.9-25.3 mg/kg, ammonium nitrogen (NH4) 6.43-13.18 mg/kg, phosphorus (P2O5) 6.43-13.18 mg/kg, potassium (K2O) 55.49-78.62 mg/kg.

2. Characteristics of the conditions for conducting field research

The research was conducted at the stationary experimental base located in the watershed area with sod-podzolic soils in the centre of the non-black soil zone of the Russian Federation, Moscow Region, SergievPosad district. The geographical coordinates of the experimental base are 56°34' north latitude, 38°09' east longitude (Fig. 2).

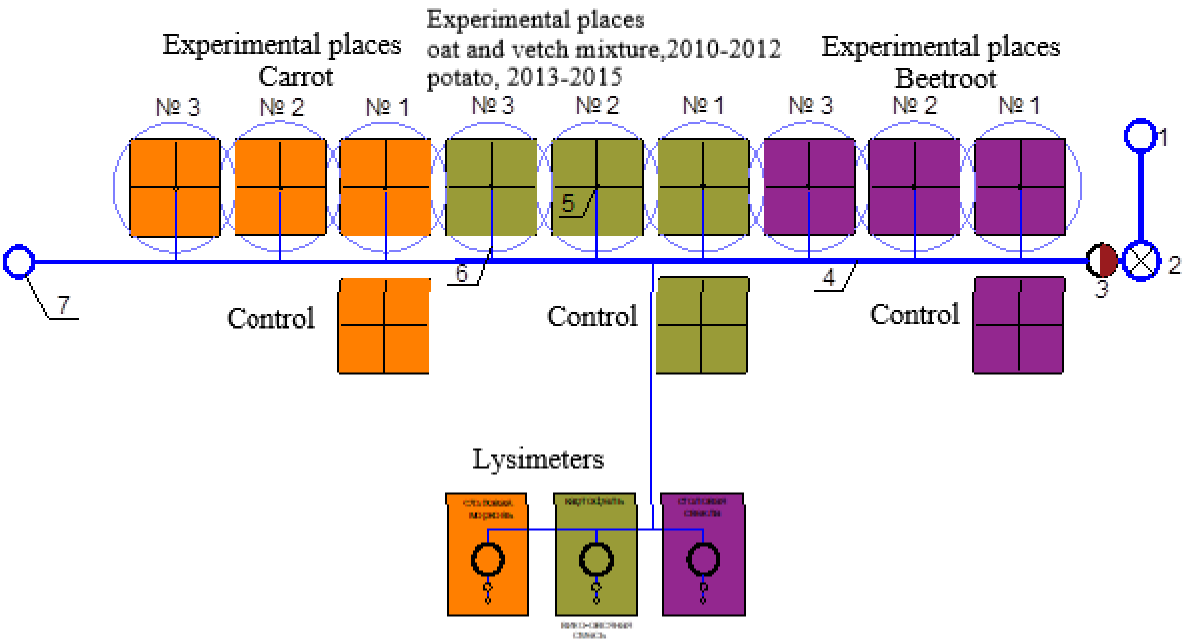


Figure 2. Scheme of the experimental base for the conducting of field experiments

1. Well on the village water supply network; 2. 3m^3 irrigation storage tank; 3. Pumping station; 4. Pressure water distribution pipeline; 5. Hydrants; 6. Irrigation pipeline; 7. Drainage well.

3. Experiment scheme

Scientific research was carried out on plots of 80 m^2 in triplicate. Options: 1 - accepted the range of soil moisture (0.6-0.7) WC (moisture capacity); 2 - also in the range (0.7-0.8) WC; 3 - also in the range (0.8-0.9) WC; 4 (control) - no watering. Watering was carried out by the Rain Bird irrigation system using nozzles with a retractable part (model 1812), sprayer consumption 0.84 m3 / h, irrigation radius 4.5 m. The agricultural technology in the experiments was standard, the doses of fertilizers: beets N80P100K90, oat and vetch mixtures N70P75K150, potatoes N90P120K120, garden carrots N100P80K15. The following observations were made: soil moisture was measured layer by layer every 0.1 m to a depth of 0.5 m, with an electric TRIME - FM moisture meter with a tubular sensor - TS. The moisture meter was calibrated using the thermostat-weight method. Total water consumption is measured on cylindrical lysimeters equipped with trays and pipes to monitor infiltration and moisture compensation. The height of the lysimeters is 1.8 m, the area is 2 m2. Soil monoliths were installed in lysimeters without disturbing its structure. Agrochemical and water-physical indicators were studied in a specialized laboratory. To process the observation results, we used the methods of regression and correlation analysis using Microsoft Office Excel 2007.

Round metal lysimeters with a tray and infiltration and compensation pipes were used to determine the total water consumption of the crops under study. The height of the cylinders of the lysimeters without pallets was assumed to be 1.8 meters and the cross-sectional area equal to two square meters. The lysimeters (Fig. 3) were installed with soil monoliths without disturbing the soil structure. Agrochemical and water-physical parameters were determined in a specialized laboratory.

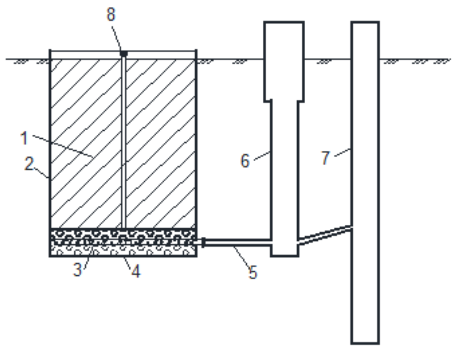


Figure 3. Lysimeter construction scheme: 1 - soil monolith; 2 - lysimeter body; 3 - drainage pipe; 4 - sump; 5 - connecting pipe; 6 - compensation pipe; 7 - infiltration pipe; 8 - moisture meter probe pipe.

4. Calculation of water consumption and irrigation regime

The total water consumption of red beet, oat-wheat mixtures, potatoes, and garden carrots was obtained using circular metal lysimeters with a pallet and compensation and infiltration pipes. The lysimeters have the following parameters: height without pallet is 1.8 m, cross-sectional area is

2 m^2. Equation of water balance (1) of aeration zone of lysimeters and calculated layer of plots has the following form (in mm):

$$\Delta \mathbf{W} = \mathbf{O}_C + \mathbf{m} \pm \mathbf{q} - \mathbf{E}, \quad (1)$$

where$\Delta \mathbf{W} = \mathbf{W}_К - \mathbf{W}_Н$ arefinal and initial soil moisture stores ;

$\mathbf{O}_C$ –rainfall; **m** –irrigation rate;

±**q** –water exchange of the root-containing soil layer with the layers below;

-**q** –soil moisture infiltration;

+**q** –recharging the aeration zone from the groundwater side**;**

E –total water consumption of the crops under the study.

All elements of the lysimeter water balance except water consumption were measured and the water consumption of red beet, oat-wick mixes, potatoes, and garden carrots was determined as the equation's uncoupling.

The potential total water consumption of crops was calculated using dependence (2), the methodology for obtaining which was proposed by V. V. Pchelkin 2015.

$$\boldsymbol{E}_{\Pi} = a \sum_{i=1}^{nd} \boldsymbol{d}_{si}^{\,b}, \quad (2)$$

where $\mathbf{E}_п$– potential water consumption of the crops under study, mm/dec;

Σ**d**si –sum of average daily humidity deficits in the i decade of the growing season, mb/dec;

nd - the number of ten-day periods during the growing season for red beet, oat-vegetable mixtures, potatoes and garden carrots;

a, b – empirical coefficients depending on climate zone, soil type and crop (Table 1).

Таблица 1. Empirical coefficients**a**andb

Empiricalcoefficients	**Agriculturalcrop**			
	Red beet	oat-vegetablemixture	Potato	Garden carrot
a	1.04	1.21	1.31	1.06

b	0.88	0.81	0.77	0.86

Crop irrigation regime was determined by calculating the water regime of sod-podzolic soils in watersheds based on retrospective analysis of climatic data. The calculation was carried out in two stages. The first stage consisted in checking convergence of actual and calculated data obtained during calculation of crop water regime and crop irrigation regime according to the program of A.I. Golovanov 1993, using the results of scientific researches outlined above. The second stage consisted in calculation of water regime and irrigation regime by meteorological data (Dmitrov city) for 45 years (1960...1998, 2010...2015) that meets requirements of SniP 2.06.03-85 that recommend to set irrigation norm for period of not less than 20-30 years.

5. Disadvantages and uncertainties

The application of the results obtained in the optimization of crop irrigation regime on sod-podzolic soils in the watershed areas of the central part of the non-black soil zone of Russia is limited by the conditions under which they were obtained.In order to remove these limitations, scientific research on the optimization of irrigation regime and the relationship of potential total crop water consumption, with the sum of average daily moisture deficit for 2010-2015 (Fig. 1-4) should be continued by other crops, soils, natural climatic zones, which were not considered in the present article.

In 2019, we started scientific research on the topic of the article under consideration with other irrigation methods (drip, subsurface). In addition, scientific research on optimizing the irrigation regime of crops on sloping land is expected to be initiated.

3 RESULTS AND DISCUSSION

An important element in calculating the irrigation regime is water consumption, for the calculation of which a number of formulas are known both in Russia and abroad. The ability to use one or another formula for water consumption of agricultural crops is associated with the need to have bioclimatic and other coefficients included in the formulas. However, these coefficients were obtained in specific natural and climatic zones, for specific crops, soils and their transfer to other conditions poses the problem of their correction and clarification (Recommendations for irrigation norms in the Non-Chernozemic Earth Zone of the RSFSR, 1984). It should be noted that biological coefficients for ten-day periods for beetroots, oat-vetch mixture, potatoes, carrots on sod-podzolic soils of the watersheds of the non-chernozem zone of the Russian Federation are absent. The existing methods for calculating water consumption do not fully or do not take into account the level of soil moisture, which significantly affects the total water consumption of plants.

3.1 Getting the formula for total water consumption

Due to the fact that analysis of known formulas for calculation of crop water consumption for research conditions showed that none of them gave results of necessary accuracy V. V. Pchelkin, S. O. Vladimirov 2015; V. O. Gerasimov 2017. Therefore, the task arose to obtain an empirical formula for calculating water consumption of red beet, oat-wheat mixtures, potatoes, garden carrots on sod-podzolic soils of watershed territories of the central part of the non-black-soil zone of Russia.

Using the data of potential total water consumption of red beet, oat-wheat mixture, potato, garden carrot and air humidity deficit for ten-day periods, statistical series for each crop were compiled and regression equations were obtained. A power function was used. The relationship between potential water consumption (**E**$_п$) of red beet, oat-wheat mixture, potato, and carrot and the sum of average daily air moisture deficit (Σ**d**si) is shown in Fig. 4.

Correlation of potential water consumption of fodder crops with the sum of average daily humidity deficits was determined for the growing season: red beet and oat-wick mixtures 2010-2012, potatoes 2013-2015, garden carrots 2015-2017. The correlation coefficient of this relationship is 0.976$\pm$0.068 for red beet, 0.974$\pm$0.050 for oat-wick mixtures, 0.947$\pm$0.089 for potato, 0.963$\pm$0.075 for garden carrot and coefficient of determination is 0.95, 0.97, 0.90, 0.93 respectively. It means that in 95, 97, 90, 93 % of cases the fluctuations of potential total water consumption of red beet, oat-vegetable mixture, potato, garden carrot in considered conditions are caused by fluctuations of humidity deficit.

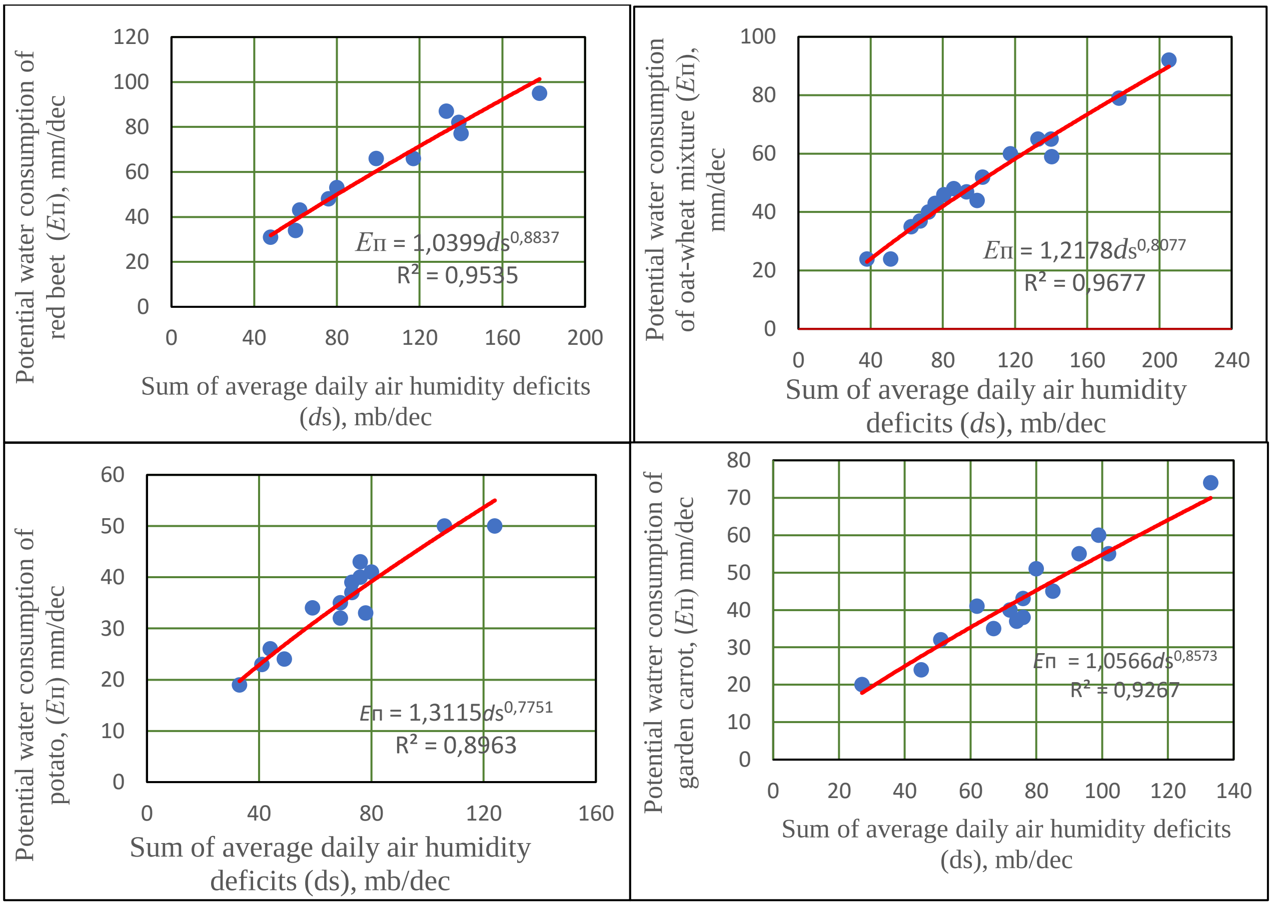


Figure 4. Correlation of potential water consumption (**E**п) of red beet (A), oat-wheat mixture (B), potato (C), garden carrot (D) with the sum of average daily air humidity deficits (Σ**d**si)

2. Biological coefficients for red beet, oat and wheat mixtures, potatoes, carrots on sod-podzolic soils

The biological specificities of the crop in the formula for calculating water consumption were taken into account by the biological coefficients (3):

$$k_б = \frac{\boldsymbol{E}\,ф}{\boldsymbol{E}\,п},$$

(3)

where**E**фis acrop water consumption determined by the water balance of the lysimeters, mm/dec;

Eпis a potential total crop water consumption calculated by formula (2), mm/day.

The results of the calculation of crop biological coefficients are summarized in Table 2.

Table 2: Biological coefficients of crops by decade

Thecultivatedplants	Decadenumber									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Red Beet [10]	0.86	0.93	0.98	1.01	1.03	1.03	1.02	0.99	0.94	0.88
Vetch and common oats mixtures [13]	0.75	0.88	0.98	1.04	1.06	1.06	1.01	0.94	–	–
Potato [12]	0.80	0.91	0.99	1.04	1.06	1.04	1.00	0.92	0.82	0.80
Garden carrot [11]	0.77	0.87	0.93	0.98	1.01	1.02	1.01	0.97	0.91	0.83

By introducing the values of biological coefficients of the crops into formula (2), the formula for calculating the total water consumption takes the following form (mm) - formula (4):

$$\boldsymbol{E}_{\mathrm{P}} = k_б a \sum_{i=1}^{nd} \boldsymbol{d}_{si}^{b}$$

(4)

Determination of the coefficients in formula (5) that take into account the deviation of soil moisture from the optimum values*.

$$\boldsymbol{E}_{\mathrm{P}} = k_w k_б a \sum_{i=1}^{nd} \boldsymbol{d}_{si}^{b}$$

(5)

* The consistency of the actual water consumption of the studied crops (plot data), with the calculated one by the formula (5) was verified in the publications of V.V. Pchelkin, M.I. Abdel Tavab, D.S. Shilnikov 2015.

Besides the biological characteristics, the total water consumption of the plants also depends on the moisture content of the root zone of the soil. In order to account for soil moisture, an appropriate coefficient (kw) should be introduced into the formula (4). In order to obtain coefficients taking into account deviation of soil moisture from optimum values we carried out experiments on experimental plots (Table 3).

Table 3: Soil moisture coefficients

Thecultivatedplants	Soilmoisture				
	0.7-0.8 MWC	0.6-0.65 MWC	0.51-0.59 MWC	0.45-0.50 MWC	0.40 MWC
Red beet [10]	1.0	0.85	–	0.48	–
Vetch and common oats mixtures [13]	1.0	0.90	0.71	–	0.40
Potato [12]	1.0	0.90	0.78	–	0.60
Garden carrot [11]	1.0	0.90	–	0.75	0.50

Table 4: Empiricalcoefficients **a** and **b**

Thecultivatedplants	a	b
Red beet [10]	1.04	0.88
Vetch and common oats mixtures [13]	1.21	0.81
Potato [12]	1.31	0.77
Garden carrot [11]	1.06	0.86

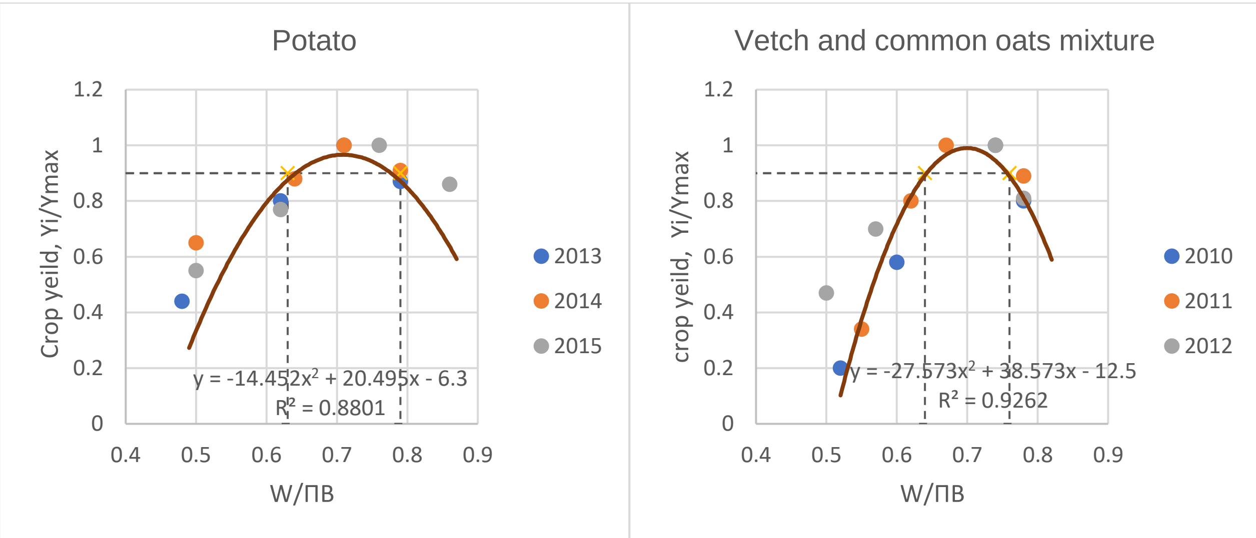
3. Limits of regulation of soil moisture for beets, oat-vetch mixtures, potatoes, carrots on sod-podzolic soils.

When calculating the irrigation regime, it is necessary to know the limits of the regulated values of soil moisture. Analysis of the data of various researchers (Alpatiev, 1954; Vaneyan, 2010; Konstantinov, 1975; Korotkov, 1984; Kostyakov, 1960; Maslov, 1974 et al).showed that there is no consensus on the permissible range of soil moisture in the conditions under consideration. The regulation limits for optimum soil moisture depend on the type of crop and type of soil. In this regard, studies were carried out on the effect of the moisture content of sod-podzolic soil on the yield of the studied crops on experimental plots in this regard (Kostyakov, 1960; Maslov, 1974; Pchelkin, 2015a).

The results are shown graphically in Figure 5.

The method of obtaining the similar curves is given in the work of V. V. Shabanov(Shabanov, 1981).

The dependence diagram between the relative values of crop yields (Y_i/Y_{max}) and moisture content of demo-podzolic soils under the conditions of sprinkling irrigation in 2010-2015 shows the close affinity between these values. The correlation factor between considered values is: red beet - 0.978±0,0724, vetch-oat mixture - 0.953±0.0948, potatoes - 935±0.111, carrot - 0.985±0.0538. The determination factor is 0.958, 0.910, 0.875 and 0.971, respectively. The maximum yield of red beet, potatoes and carrot was observed at soil moisture content of 0.71 maximum water capacity and vetch-oat mixture - 0.70 maximum water capacity. It is technically difficult and economically expensive to keep such a value in actual practice, so it is rationally to use the soil moisture range. A. R. Konstantinov(Konstantinov, 1975) recommends to reduce the crop yield by 10-15% of the maximum value. Using this assumption and reducing the crop yield by 10 % of maximum values, we`ll obtain the following optimal ranges of the moisture content for demo-podzolic soils: red beet (0.64 - 0.78) maximum water capacity, vetch and common oat mixture (0.64 - 0.77) maximum water capacity, potato (0.63 - 0.79) maximum water capacity, garden carrot (0.65 - 0.78) maximum water capacity.



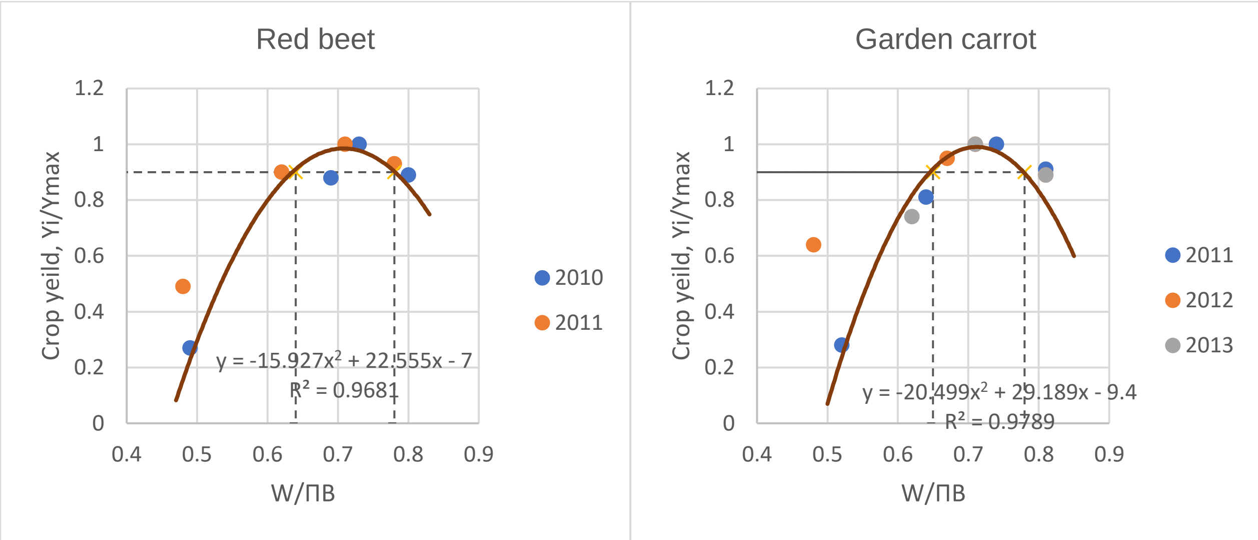


Figure 5: Regularity of changes in the relative crop yield ($Y=Y_i/Y_{max}$) against the moisture content of demo-podzolic soils under the conditions of sprinkling irrigation: Maximum water capacity=0.42 cm^3/cm^3; Y_i – crop yield in a specific year, t/ha; Y_{max} – maximum yield in the same year

The formula for calculating the irrigation rate includes the value of the calculated soil layer, which is due to the depth of root propagation and depends on the agricultural crop and the phase of its development.

Analysis of the literature on the crops under consideration shows that there is no consensus among researchers on the choice of the thickness of the calculated soil layer (Vaneyan, 2010; Korotkov, 1984; Kostyakov, 1960;Kharchenko, 1987 et al.). Therefore, studies were carried out on the experimental site, which made it possible to link the numbers of decades with the depth of the calculated layer of sod-podzolic soil for the studied crops. The depth of the calculated layer of sod-podzolic soil is presented in Table 4.

The analysis of the table shows that from the first to the third decade the calculated layer should be 20 cm, from the fourth to the fifth decade - 30 cm, from the sixth decade onwards 40-50 cm.

Table 4: The depth of the calculated layer of agricultural crops when irrigating sod - podzolic soils

Thecultivatedplants	**Decadenumbers**								
	1-2	**1-4**	**3-4**	**3-5**	**5-6**	**5-8**	**5-9**	**7-9**	**7-10**
Red beet [10]	10	–	20	–	–	40-50	–	–	–
Vetch and common oatsmixtures [13]	20	–	30	–	–	–	40-50	–	–
Potato [12]	20	–	–	30	–	–	–	40-50	–
Garden carrot [11]	–	20	–	–	30	–	–	–	40-50

4.Irrigationnorms

The irrigation norm during the vegetation period of the plants is supplied in portions, linking it to the growth and development of the root system and the water requirements. The irrigation norm is determined by the formula of A.N. Kostyakov 1960.

m = (W2 –W1)h,

(6)

Where mis irrigation norm, mm;

hiscalculation layer, mm;

W1, W2 arevolumetric moisture and depths of the calculated soil layer before and after irrigation, (cm^3/cm^3).

An irrigation rate of 10 mm or 100 m^3/ha for non-vegetation irrigation is quite acceptable, as there is no point in moistening the soil layer deeper than 70 mm. It must be taken into account that sod-podzolic soils have low fertility. Therefore the vegetative irrigation rate should not exceed 40 mm or 400 m^3/ha, as there is a risk of leaching nutrients from the root layer into the deeper horizons (Table 5).

Table 5: Results of the irrigation rates determination

Thecultivatedplants	Non-vegetationirrigation , мм		Vegetationirrigation , мм		
	pre-sowing	postplant	**The decade number**		
			1-3	4-5	6-10
Red beet	10	10	20	30	40
Vetch and common oats mixtures	10	10	20	30	40
Potato	10	10	20	30	40
Garden carrot	10	10	20	30	40

5.Irrigationregime

In the central part of the non-black-soil zone of Russia, atmospheric precipitation, total water consumption, and moisture infiltration into deep horizons have the main influence on soil moisture. In dry years and dry periods, soil moisture becomes below the minimum allowable values. Therefore crop irrigation is necessary during these periods. When designing irrigation systems it is necessary to calculate the irrigation regime.

A number of mathematical models are known in the literature and are described in the following works (Golovanov, 1993; Kharchenko, 1987; Cid – Garcia, 2014; Melikhova, 2019; Ovchinnikov, 2018 et al.).Comparative analysis has shown that the mathematical model of A. I. Golovanov, 1993 is the most acceptable for calculation of crop irrigation regime for irrigated sod-podzol soils, watersheds. However, taking into account the conducted scientific research, this model has been upgraded in the following respects:

1. The permissible limits of moisture control of sod-podzolic soils in the cultivation of red beet, oat-wheat mixtures, potatoes, and garden carrots have been established.

2.Empirical formula obtained by the authors for calculation of total water consumption by agricultural crops was used. It determined values of biological coefficients and coefficients taking into account deviation from optimal values of moisture content in sod-podzolic soils.

3. The depth of the calculated layer of sod-podzolic soils during the growing season of red beet, oat-wheat mixtures, potatoes and garden carrots was determined.

The irrigation regime for agricultural crops according the modified Golovanov model (1993) was determined when calculating the water regime of sod-podzolic soils in watersheds based on a retrospective analysis of climatic data. The calculation was carried out in two stages. The first stage consisted of checking the convergence of the actual and calculated data obtained in the course of calculating the water regime and the irrigation regime for agricultural crops according to the program of A.I. Golovanov(Golovanov, 1993), using the results of research outlined above. The second stage consisted of calculating the water regime and irrigation regime according to meteorological data (Dmitrov city) for 45 years (1960 ... 1998, 2010 ... 2015), which corresponds to the requirements of the Building Norms and Rules 2.06.03-85, which recommend setting the irrigation norm for a period of at least 20-30 years. The results of calculating irrigation regimes for the crops under consideration in the conditions of sod-podzolic soils of watersheds are summarized in Table 5.

Table 5: Irrigation regime for agricultural crops on sod-podzolic soils of the watersheds of the Moscow region* (calculated data)

P, %	Irrigationrate, mm	Irrigationrates (mm)				Waterexchange, mm	Depthofgroundwater (cm)	Calculatedsoillayer, cm
		Beetroot [10]	Oat and VetchMixtures [13]	Potatoes [12]	Carrot [11]			
5	20…40	<u>310</u> 8-9	<u>320</u> 10-11	<u>282</u> 9-10	<u>310</u> 8-9	0…-33	400- 420	20…40
10	20…40	<u>235</u> 6-7	<u>265</u> 6-7	<u>224</u> 7-8	<u>250</u> 6-7	-22…-44	380- 401	20…40
25	20…40	<u>121</u> 3-4	<u>160</u> 3-4	<u>169</u> 5-6	<u>140</u> 3-4	-32…-63	360- 401	20…40

50	20…40	80 2-3	105 2-3	107 3-4	80 2-3	-66…-96	340- 401	20…40
75	20…40	40 0-1	70 0-2	84 2-3	60 0-2	-94…-157	320- 401	20…40

*) Note: the numerator is the irrigation rate; the denominator is the number of waterings.

Figure 1 shows the relationship between the actual values of irrigation norms and those calculated using the modernized mathematical model of A.I. Golovanov. The correlation coefficient of this relationship is 0.972 + 0.078, which indicates a close relationship between M_f and M_r.

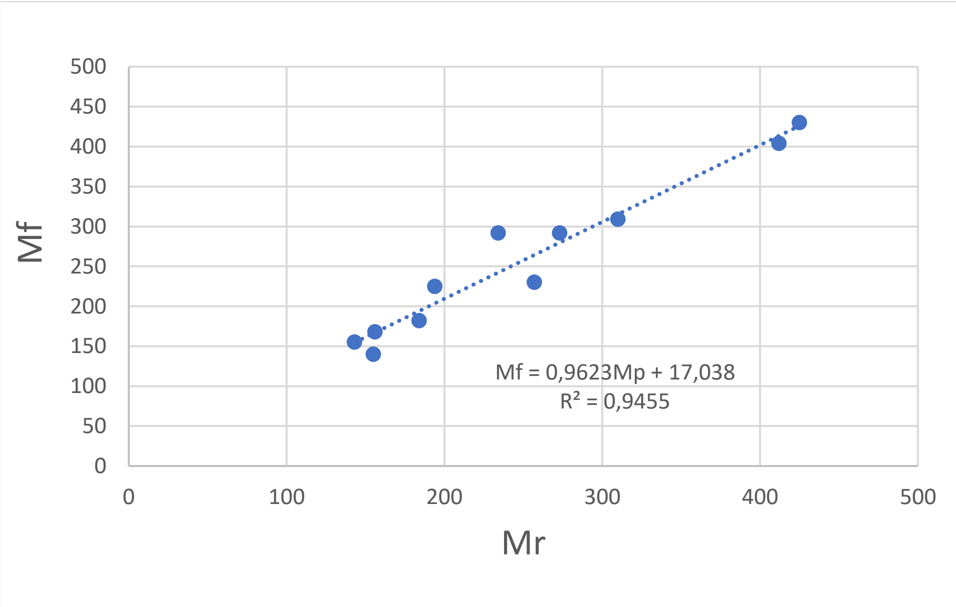


Figure 1: The relationship of the actual values of irrigation norms (M_f) with the calculated M_r

Table 6 shows the irrigation norms recommended by research organizations for the Moscow region for comparative analysis.

The analysis of tables 5 and 6 shows that the irrigation norms obtained during the development and justification of the irrigation regime (Table 5) are not contradictory in comparison with the irrigation norms recommended by other authors (Table 6). However, a comparison of the data in Table 5 and Table 6 indicates some of their differences.

Table 6: Irrigation rates (mm) of agricultural crops for the conditions of the Moscow region

Recommendations	Provisionwith**Oc**, %		
	5	25	50
Betroot			
GGI Kharchenko S.I. [19]	250	200	130

VNPO "Raduga" [16]	210	110	70
SevNIIGiM [18]	152	102	50
VNIIGiM [15]	190	-	-
Oat-VetchMixtures			
SevNIIGiM [18] VNPO	208	126	102
"Raduga" [17] VNIIGiM [15]	250	130	90
VNII feed [9]	185	115	70
	233	156	25
Potato			
VNIIGiM [15]	280	180	130
VNPO "Raduga" [16]	150	90	70
SevNIIGiM [18]	110	99	88
Research Institute of Vegetable [4]	-	140	-
Carrot			
GGI Kharchenko S.I. [19]	-	100	80
VNIIGiM [15]	200	150	120
VNPO "Raduga" [16]	210	110	70
SevNIIGiM [18]	152	102	50
Research Institute of Vegetable [4]	-	-	50-80

Recommended irrigation rates for beetroots: GGI (Shabanov, 1981), VNPO “Raduga” (Recommendations on the regime of irrigation of agricultural crops in the Moscow region, 1982),SevNIIGiM [19] and VNIIGiM(Kharchenko, 1987), differ from those obtained by calculation (modernized mathematical model of A.I. Golovanov) in a dry year 5% supply downward, respectively, at 1.24; 1.48; 2.04; 1.63 times. In an average year (50%), the irrigation norms recommended by the State Property Institute are overestimated by 1.65 times, and the recommended ones: VNPO “Raduga” and SevNIIGiM are underestimated, respectively, by 1.10 and 1.19 times. In a moderately dry year in terms of moisture content, 25% of the GHI supply is overestimated by 1.65 times, and VNPO “Raduga”, VNIIGiM underestimated by 1.10 and 1.19, respectively.

Irrigation norms for Oat-Vetch Mixtures, according to the recommendations of SevNIIGiM, VNPO “Raduga”, VNIIGiM, VNIIkormov, are underestimated in an average-dry year in terms of moisture, respectively, by 1.27; 1.23; 1.39 and 1.02 times, and an average of 1.03; 1.17; 1.50; 4.2 times. In a dry year, SevNIIGiM, VNPO “Raduga”, VNIIGiM, VNIIkormov understate the irrigation rate, respectively, by 1.54; 1.16; 1.73; 1.37 times.

The irrigation rate for potatoes, recommended at 5% supply by VNIIGiM, practically coincides with the calculated ones, the deviation towards underestimation is 1.01. The underestimations of VNPO "Raduga" and SevNIIGiM are more significant and amount to 1.88 and 2.56 times. In a mid-dry year, the value of irrigation norms recommended by VNIIGiM gives an overestimate by 1.07 times, VNPO "Raduga", SevNIIGiM and Research Institute of Vegetable Growing underestimate, respectively, by 1.88; 1.70; 1.21 times. In an average year, the irrigation norms recommended by VNPO "Raduga" coincide with the calculated ones, while VNIIGiM and SevNIIGiM overestimate by 1.86 and 1.26 times, respectively.

Irrigation rates for canteen carrots recommended for dry years by VNIIGiM, VNPO "Raduga", SevNIIGiM give an underestimation, respectively, in 1.55; 1.48; 2.04 times. In an average dried year in terms of moisture content, 25% of the supply of VNIIGiM gives an overestimate by 1.65 times, and VNPO "Raduga", VNIIGiM underestimates by 1.10 and 1.19, respectively. In an average year, the irrigation rates recommended by GGI, VNIIGiM, VNPO "Raduga" overestimate 1.33; 2.00; 1.17 times, and SevNIIGiM underestimation 1.20 times. The calculated irrigation rate is included in the range of irrigation rates recommended by the Research Institute of Vegetable Growing.

The increase in the irrigation rate at 5% supply in Table 5 is higher than in Table 6, due to the inclusion in the calculations (Table 5) of the temperature and relative importance of the air of the anomalous 2010.

Thus, the results of Table 5 and the close correlation and consistent data with scientific organizations (Table 6) make it possible to recommend the modernized mathematical model of A.I. Golovanov for calculating design irrigation regimes for agricultural crops and making forecasts of the water regime of sod-podzolic soils in watershed areas for a long-term period.

4 CONCLUSIONS

To ensure stable and efficient production of agricultural products in the Center of the Non-Black Earth Zone of Russia, irrigation land reclamation is required. Irrigation method is sprinkling. The conducted scientific research is unique because on sod-podzolic soils of watersheds of the central part of the non-black soil zone of Russia at cultivation of red beet, oat-wheat mixtures, potato, garden carrot the formula for calculation of total water consumption of researched crops is developed. At the same time, numerical data on empirical, biological coefficients and coefficients taking into account decrease of soil moisture below optimal values, as well as on optimal limits of soil moisture regulation and calculated soil layers under deep groundwater were obtained. In addition, the mathematical model for calculating the irrigation regime was upgraded, using which the irrigation regime was calculated for the studied crops and years with different water balance deficit security.

To save irrigation water and obtain high yields of agricultural crops on sod-podzolic soils of watersheds, it is advisable to use the proposed equations for calculating water consumption. Biological coefficients must be differentiated according to the growing seasons of agricultural crops. The optimal limits for regulating soil moisture should be applied for table beets (0.64-0.78), vetch-oat mixture (0.64-0.77), potatoes (0.63-0.79), carrots (0.65 –0.78) maximum for water. The calculated layer of soil moisture in deep groundwater should be 0.1–0.5 m for table beets, vetch-oat mixture, potatoes, carrots 0.2–0.5 m. The results of calculations on mathematical models must be checked with data from field experiments.

As a result of the conducted research, the scientific community received a methodology of scientific knowledge on the optimization of crop irrigation regime on sod-podzolic soils of the watersheds of the central part of the non-black soil zone of Russia and new previously unknown scientific knowledge.

Design firms are advised to use a formula to calculate the total water consumption of the crops under study, empirical, biological coefficients and coefficients that take into account the reduction in soil moisture. Optimal soil moisture control limits and design soil layer for deep groundwater. An upgraded mathematical model for calculating the irrigation regime. Farmers are recommended to use the results of scientific research in the operation of irrigation systems.

Optimization of the irrigation regime in this article allows to increase the yield of agricultural crops and save water resources.Politicians should orient agricultural production towards the implementation of such scientific developments and incentivize them economically.

Legislators should adopt laws allowing for the accelerated introduction of scientific developments in irrigated land reclamation into agricultural production.

In the future, we plan to expand the research with other crops and other irrigation methods.

5. ACKNOWLEDGMENTS

The present scientific researches were carried out within the grant of the Ministry of Education and Science of the Russian Federation № 075-15-2021-032 from 23.03.2021 for establishment and development of the engineering centre on the base of an educational organization of higher education and (or) scientific organization within the federal project "Development of infrastructure for scientific research and personnel training" of the national project "Science and Universities".

REFERENCES

Alpatiev A.M. (1954). Moisture turnover of cultivated plants. Leningrad: Gidrometeoizdat,22-130.

Alpatiev A.M., Ostapchik V.P. (1971). To the substantiation of the formation of irrigation norms using the bioclimatic method for calculating the total evaporation. Melioration and water management, 19, 13-17.

Budyko M.I. (1956). Thermal balance of the earth's surface. Leningrad: Gidrometeoizdat,256.

Vaneyan, S.S., Menshikh A.M. (2010) Irrigation regime, methods and techniques for watering vegetables and melons in various zones of the Russian Federation. Management. Moscow: The All-Russia Research Institute of Legumes and Groat Crops,82.

Golovanov A.I. (1993). Optimization of irrigation regimes for chernozems. Pochvovedenie. 6, 79-84.

Danilchenko N.V. (1982). Methodological features of calculating irrigation norms of agricultural crops in the non-chernozem zone of the RSFSR. Technique and technology of mechanized irrigation. Moscow, 177-186.

Dubenok N.N. (1984). Sprinkling irrigation of slope areas in the non-chernozem zone of the RSFSR. Izvestiya TSKHA. No. 2.

Konstantinov A.R. (1975). Determination of the optimal moisture content of the soil by the periods of development of winter wheat.Hydrotechnics and melioration, 2, 38-43.

Korotkov B.I. (1984). Irrigated pastures and hayfields from the non-chernozem region. Moscow.Rosselkhozizdat, 21-77.

Kostyakov A.N. (1960). Basics of land reclamation. Moscow: Selkhozgiz, 62-66.

Maslov B.S. (1974). Zoning of humidification norms for the central non-chernozem zone. Hydrotechnicsand melioration, 4, 33-40.

Pchelkin V.V., Abdul Tawab M.I., Shilnikov D.S. (2015). The relationship of evaporation from the water surface with water consumption of beetroot and vetch-oat mixture in the non-chernozemic zone of Russia.Reports of the Timiryazev Agricultural Academy, 286-2, 3-5.

Pchelkin V.V., Vladimirov S.O. (2015). Irrigation regime for carrots on sod-podzolic soils of the watershed areas of the Moscow region. Prirodoobustroystvo. 5, 78-82.

Pchelkin V.V., Gerasimov V.O. (2017). Justification of the regime of irrigation of potatoes on sod-podzolic soils of the watershed areas of the Moscow region. Scientific life, 8, 34-41.

Recommendations for irrigation norms in the Non-Chernozemic.(1984). Earth Zone of the RSFSR, 1-10.

Recommendations for the regime of irrigation of vegetable crops in the Moscow region. (1978). Kolomna, 25.

Recommendations on the regime of irrigation of agricultural crops in the Moscow region. (1982). Kolomna, 20.

Recommendations for calculating the parameters of the drainage and humidification regime of agricultural lands. (1981). SevNIIGiM. Leningrad, 54-64.

Kharchenko S.I. (1987). Water regime management on reclaimed lands in the Non-Chernozem zone.Moscow, Gidrometeoizdat, 206-208.

V. V. Shabanov. (1981). Moisture provision of spring wheat and its calculation. L.: Gidrometeoizdat,82-85.

Awady M.N., Vis E.G., Kumar R., Mitra S. (2003). Distribution uniformity from pop-up sprinklers. 15 th An. Conf. MSAE, 181-194.

Badr A.E., Bakeer G.A., El-Tantawy M.T., Awwad A.H. (2006). Sprinkler and trickle irrigation affected by climatic conditions in upper Egypt. Misr J. Ag. Eng., 23(2), 346-361.

Christiansen, J.E. (1942). Irrigation by Sprinkling. Bulletin 670. California Agricultural Experiment Station, Universityof California: Berkeley, CA, USA.

Cid-Garcia N.M., Bravo-Lozano A.G., Rios-Solis Y.A. (2014). A crop planning and real-time irrigation method based on site-specific management zones and linear programming. Computers and electronics in agriculture.https://doi.org/10.1016/j.compag.2014.06.002FAO. (1985). Introductionto Irrigation. Irrigation Water Management. Training Manual No. 1.

Hagan R.M., Haise H.R., Edminster T.W. (1987). Irrigation of Agricultural Lands. American Society of Agronomy Publ. No. 11: Madison, USA.

Heerman D.F., Martin D.L., Jackson R.D., Slegman E.C. (1990). Irrigation scheduling control and techniques. CSSA - SSSA. 677 sothseqoe rood, madiso, Wi 53711. USA. Irrigation of agriculture crops-Agronomy Monograph, 30.

Melikhova, E.V.,RogachevA.F., Skiter N.N. (2019).Information System and Database for Simulation of Irrigated Crop Growing.Studies in Computational Intelligence,826, 1185-1190.

NastaranBasiriJahromi, Amy Fulcher, Forbes Walker & James Altland. (2020). Photosynthesis, growth, and water use of Hydrangea paniculata 'Silver Dollar' using a physiological-based or a substrate physical properties-based irrigation schedule and a biochar substrate amendment. Irrigation Science, 38, 263-274.

OvchinnikovA.S., Borodychev V.V., Lytov M.N., Bocharnikov V.S., Fomin S.D., Bocharnikova O.V., Vorontsova E.S. (2018).Optimum control model of soil water regime under irrigation [Tekst].Bulgarian journal of agricultural Science, 24 (5), 909-913.

Barker J.B., Franz T.E., Heeren D.M., Neale C.M.U., Luck J.D. (2017). Soil water content monitoring for irrigation management: A geostatistical analysis.Agricultural water management, 188. 36-49. Retrieved from https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1491&context=biosysengfacpub

Evett S. R., Stone K. C., Schwartz R. C., O'Shaughnessy S. A., Colaizzi P. D., Anderson S. K., David J. Anderson (2019). Resolving discrepancies between laboratory-determined field capacity values and field water content observations: implications for irrigation management. Irrigation Science.37(6),751-759.10.1007/s00271-019-00644-4