AF-797
[1-6]

RESEARCH ARTICLE Indian Journal of Agricultural Research

Influence of Hydrothermal Parameters on Potato Irrigation Regime

V.A. Vedeneeva[1], Y.N. Potashkina[1]

10.18805/IJARe.AF-797

ABSTRACT

Background: The article presents the results of studies that allow us to calculate and predict the water consumption of cultivated vegetable crops depending on the moisture availability of the growing season. Hydrothermal indicators of the territory during the entire growing season have a significant impact on the irrigation regime and water consumption of cultivated crops.

Methods: In the present study, the assessment of natural moisture during the growing season was determined by the hydrothermal coefficient (GTC) according to the criterion of T.G. Selyaninov. The irrigation rate was calculated according to the modified formula of A.N. Kostyakov. Biological productivity was taken into account by the method of meter sites in three-fold repetition.

Result: The value of the irrigation norm varies depending on the intensity of atmospheric droughts when growing potatoes in the conditions of the dry-steppe zone of the Lower Volga region. To maintain a given pre-irrigation threshold of soil moisture, it is necessary to take into account the hydrothermal indicators of the territory during the entire growing season. The use of modern resource-saving irrigation methods, such as drip irrigation, makes it possible to ensure an uninterrupted supply of moisture to plants and, as a result, to obtain high-quality crop yields. Thus, to obtain high and stable yields of potatoes grown on drip irrigation, depending on the heat and moisture availability of the growing season, it took from 2,250 to 3,040 m3/ha of irrigation water.

Key words: Hydrothermal coefficient, Irrigation rate, Irrigation regime, Potatoes.

INTRODUCTION

Cultivation of vegetable crops in the climatic conditions of the Volgograd region without irrigation is almost impossible. The sharply continental climate of the region, lack of moisture and abnormally high air temperatures combined with dry winds in summer lead to a decrease in the efficiency of land use and crop yields. The purpose of the study is to determine the influence of moisture availability during the vegetation period of the year on the change in the value of irrigation rates required for potato cultivation in the dry-steppe zone of the Lower Volga region. We have put forward a scientific hypothesis: When calculating the values of irrigation and irrigation rates it is necessary to take into account the hydrothermal indicators of the territory throughout the growing season of potatoes. Heat and moisture are one of the main determining factors of plant life (Haider and Ullah, 2020). To assess these agro-climatic resources, one of the complex indicators, the hydrothermal coefficient (HTC) of G.T. Selyaninov, has been most widely used. The assessment of natural moisture during the growing season shows that the numerical value of the HTC is in the range from 0.50 in the southeast to 0.85 in the northwest of the Volgograd region-the zone of dry farming. The global change in climatic conditions is accompanied by an increase in climate aridity, therefore, the analysis of the main climatic factors deserves special attention and study when calculating the irrigation regime of crops (Kleshchenko *et al*., 2016; Litovchenko, 2011). One of the main and most popular vegetable crops grown in the Volgograd region is potatoes. According to the Federal State Statistics Service (2021), potatoes are cultivated in an area of about 11.1 thousand hectares, while the average yield in the region is 17.20 t/ha (Federal State Statistics Service, 2020). The yield of potatoes in farms of all categories of the region can reach 30-40 t/ha. Obtaining such high and economically justified yields in difficult climatic conditions of the region is possible with a sufficient level of agricultural technology and the use of modern irrigation methods (Kireicheva and Karpenko, 2015). Therefore, the substantiation of the influence of hydrothermal indicators and their consideration in the calculation of irrigation norms is an urgent area of research (Zwolinski and Bondarenko, 2015).

In the studies of other scientists, it is also noted that precipitation falling during the growing season in different years plays a significant role in water availability of potato plantations. In spring they account for about 25-35%, in summer about 10-15% of the total value of total water consumption. Studies and main results related to irrigation practices and hydrothermal indicators allow obtaining in arid regions yields of 30-50 t/ha of potato tubers at spring planting and up to 35 t/ha at summer planting (Ovchinnikov and Filimonov, 2008; Ovchinnikov *et al*., 2012; Ovchinnikov *et al*., 2017).

[1]Federal Scientific Centre of Agroecology, Complex Melioration and Protective Afforestation of the Russian Academy of Sciences (FSC of Agroecology RAS), Volgograd-400062, Russia.

Corresponding Author: V.A. Vedeneeva, Federal Scientific Centre of Agroecology, Complex Melioration and Protective Afforestation of the Russian Academy of Sciences (FSC of Agroecology RAS), Volgograd-400062, Russia. Email: varusha-f@mail.ru

How to cite this article: Vedeneeva, V.A. and Potashkina, Y.N. (2023). Influence of Hydrothermal Parameters on Potato Irrigation Regime. Indian Journal of Agricultural Research. DOI: 10.18805/IJARe.AF-797.

Submitted: 02-07-2023 **Accepted:** 09-08-2023 **Online:** 24-08-2023

Since the study region is located in steppe and semi-desert natural zones, we selected representative plots on agricultural land in two farms. Soil conditions of the study sites are typical for this region. Tumak farm is characterized by floodplain-meadow soils, humus content in arable layer is 2.73%. The mechanical composition of soils is heavy loamy with nutty, finely lumpy structure. The soils of Mayskiy settlement are light-chestnut solonetz, slightly solonetz, heavy loamy, humus-poor. The humus content in the arable layer is in the range of 1.65-1.98%. The results of the research are relevant for a large number of agricultural producers engaged in potato cultivation in the conditions of the dry-steppe zone. For the Volgograd region, as one of the key agrarian regions, the preservation of yields and maintenance of optimal conditions for cultivation is of paramount importance.

MATERIALS AND METHODS

The research was conducted at the FSC of Agroecology RAS within the framework of the state assignment No FNFE-2022-0007 "Theory and principles of formation of adaptive agroforestry complexes of the dry-steppe zone of the south of the Russian Federation in the context of climatic changes".

The object of the study was the agrocenosis of potatoes grown on irrigated lands of the dry steppe zone of the Volgograd region (Fig 1).

The assessment of natural moisture (Rusiva, 1967) during the growing season was determined by the hydrothermal coefficient (GTC) according to the criterion of T.G. Selyaninov (Formula 1):

$$K = R * 10 / \sum t \qquad ....(1)$$

R- Sum of precipitation for the period with air temperatures above +10°C (mm).

Σt- Sum of air temperatures for the same time, (°C).

Meteorological data were obtained at the nearest weather station from the research site (Climate data archive, 2023). The research was carried out in the Sredneakh tubinsky district of the Volgograd region, the Tumak farm in 2020 (object coordinates N 48°3642.108; E 44°3839.446) and the Mayskiy settlement of Volgograd in 2021 (object coordinates: N 48°3131631; E 44°1032513). Irrigation system-drip irrigation, tape produced by T-tape.

The irrigation rate was calculated according to the modified formula of A.N. Kostyakov and according to the manual to SNiP (building codes) 2.06.03-85 "Drip irrigation" (Kostyakov, 1960) (Formula 2,3,4).

$$m = \frac{(V * t)}{F} \qquad ....(2)$$

V- Volume of water supply to the irrigated plot during one hour, m^3.

F- Gross irrigated area, ha.

t- Duration of irrigation, h.

$$t = \frac{V}{g} \qquad ....(3)$$

t- Irrigation time,h;

V- Volume of water supply, l;

g- Flow rate of one dripper, l/h.

$$V = a * b * h * a * (WHB - \Lambda\ WHB) \qquad ....(4)$$

V- Volume of water supply to any section of the humidifier served by one dropper, m^3 or l.

a- Distance between drippers, m.

b- Width of moistening strip, m.

h- Depth of wetting, m.

Λ- Coefficient of pre-watering soil moisture, corresponding to the lower boundary of moistening, in fractions of one.

WHB- Lowest soil moisture capacity, %.

Phenological observations were carried out in the following phases of potato development: planting-shoots, shoots-budding, budding-flowering, flowering-termination of the growth of the tops, termination of the growth of the tops -wilting of the tops, wilting of the tops-full ripeness. For each phase, the beginning was noted when 10% of plants entered it and the mass offensive when it was established in 75% of plants. Biological productivity was taken into account by the method of meter sites in three-fold repetition (Litovchenko, 2011; Pleshakov, 1983; Vedeneeva and Ruleva, 2021).

RESULTS AND DISCUSSION

The HTC calculated for the entire growing season does not always allow an objective assessment of the class of drought in intensity. A more detailed analysis of the HTC by periods (months) of vegetation of crops is needed.

According to the temperature regime, the years of research differed significantly, during the growing season the sum of active temperatures varied from 1808 to 1962°C. The amount of precipitation was 162.3 and 169.3 mm, respectively, but in 2020 they were unevenly distributed.

In 2020, according to the category of the intensity of atmospheric droughts, April was characterized as slightly arid, there was no drought in May, but precipitation was stormy and was unevenly distributed during the month. There was a severe drought in June and a very severe drought in July. In general, the growing season is dry (Table 1).

In 2021, the value of the HTC decreased evenly by month, according to the category of intensity of atmospheric droughts in April there was no drought, in May and June there was a weak drought, in July there was a severe drought. In general, the growing season was dry (Fig 2).

For normal growth, development and full ripening of potato varieties of different ripeness groups, the sum of active temperatures (above 10°C) during the growing season should be in the following ranges: for early and medium-early-from 1000 to 1400°C; for medium-ripe - from 1400 to 1600°C; for medium-late and late - from 1600 to 2200°C. Considering that the sum of active temperatures for the growing season in 2020 and 2021 amounted to 1808°C and 1962°C, respectively, it can be concluded that potatoes of various ripeness groups can be grown in the areas of our research.

Potatoes are a demanding crop for soil moisture and water-air regime. The optimal moisture content in the soil for plant growth and the formation of a high yield of tubers on light soils is 75-80% of the lowest soil moisture capacity (LMC), medium-70 and heavy-50-60% LMC. The need for moisture in potatoes differs significantly in the growth phases. The phase of the beginning of flowering is a critical period and, with insufficient water supply, leads to a decrease in the yield of potato tubers to 50-60%. Short-term droughts in the budding phase reduce the yield of tubers by 17-23% (Olgarenko *et al*., 2019; Ovchinnikov *et al*., 2017). The experience of domestic and foreign potato producers shows that productivity growth in arid climates is possible based on the use of modern irrigation methods and agricultural

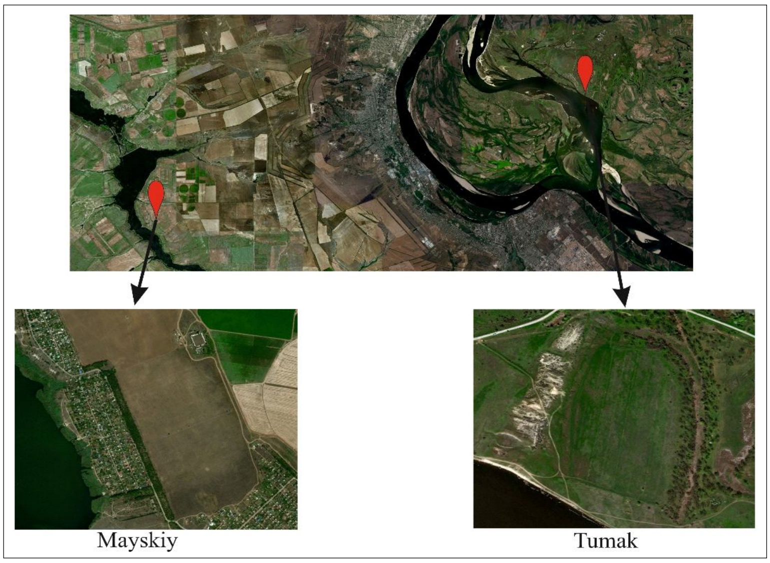

Fig 1: A space map of research objects.

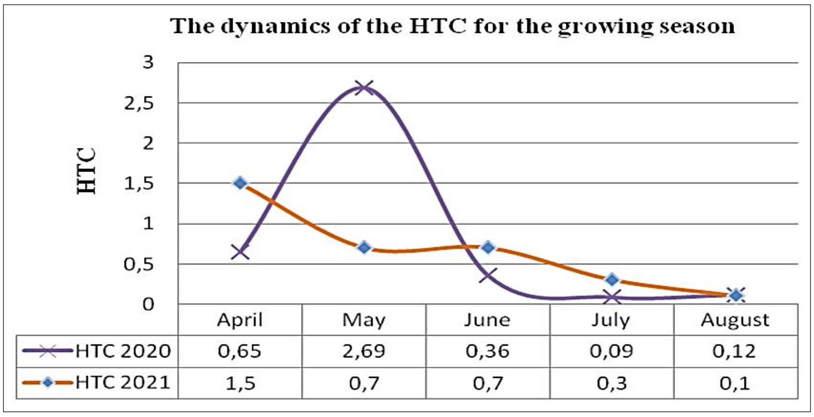

Fig 2: Change in the hydrothermal coefficient during the growing season of potatoes.

Table 1: Class of droughts by intensity.

Month	April	May	June	July
		(2020)		
HTC of selyaninov	0.65	2.69	0.36	0.09
Drought assessment indicator	Mild drought, class 4	Absence of drought, class 5	Severe drought, class 2	Very severe drought, class 1
		(2021)		
HTC of Selyaninov	1.5	0.7	0.7	0.3
Drought assessment indicator	Absence of drought, class 5	Mild drought, class 4	Mild drought, class 4	Severe drought, class 2

technology, which allows for prompt regulate the water, temperature and food regimes of agrocenosis (Olgarenko, 2014). Drip irrigation was used in our studies.

The irrigation rate, the duration of irrigation and the number of irrigations changed during the growth and development of the plant. In 2020, according to the calculations, in the interphase period “planting sprouts”, to maintain a given level of soil moisture, it was necessary to carry out 5 irrigations at a rate of 110 m^3/ha for a duration of 1.5 hours (Table 2). For the same growing season in 2021, it was required to carry out 2 irrigations at a rate of 200 m^3/ha for a duration of 3 hours. The irrigation rate was 550 and 400 m^3/ha for the years, respectively. At the same time, in 2020, this growing season was dry (HTC = 0.65), while in the same period of the following year, there was no drought (HTC = 1.5). Consequently, depending on the emerging hydrothermal indicators, the irrigation norm changes by 27%. During the period of “shoots-budding”, when there was an intensive increase in the vegetative mass of the plant, the number of watering was increased. To maintain soil moisture at the required level in 2020, it was necessary to carry out 8 irrigations with a norm of 110 m^3/ha lasting 1.5 hours. Next year, 5 irrigations were carried out at a rate of 150 m3/ha with a duration of 2.0 hours. The irrigation norm was 880 and 750 m^3/ha by year, respectively. At that, in 2020 this growing season was wet (HTC = 2.69) and the same period of the next year was slightly dry (HTC = 0.7). Consequently, depending on the emerging hydrothermal indicators, the irrigation norm changes by 15%.

In the “budding-flowering” phase, when tuber formation began, according to the intensity of atmospheric droughts, a severe drought was noted in 2020 and a weak drought in 2021. At the same time, in 2020 it was necessary to carry out 2 watering and in 2021-1 watering. The irrigation rate for this period was 146 m^3/ha and 100 m^3/ha by year, respectively. In 2020, this growing season was severely dry (HTC = 0.36) and the same period of the next year was slightly dry (HTC = 0.7). Consequently, depending on the emerging hydrothermal indicators, the irrigation rate varies by 32%.

In the phase “flowering-yellowing of the lower leaves” in 2020, it was necessary to carry out 20 watering with a norm of 73 m^3/ha lasting 1.0 hours and 5 watering with a norm of 200 m^3/ha lasting 3.0 hours in 2021. This period was drier in 2020. The irrigation rate was 1,460 and 1,000 m3/ha, respectively, according to years of research. So in 2020 this growing season was very dry (HTC = 0.09) and the same period of the next year was very dry (HTC = 0.3). Consequently, depending on the emerging hydrothermal indicators, the irrigation rate varies by 32%.

The irrigation rate and the number of irrigations varied depending on the prevailing hydrothermal conditions of each period. The value of the irrigation norm for the entire growing season in 2020 was 3036 m^3/ha and in 2021 2250 m^3/ha. Taking into account the emerging hydrothermal indicators, the irrigation norm of the growing season changes by 26%.

Table 2: Irrigation regime by phases of potato growth and development.

Vegetation period	Planting-shoots			Shoots-budding			Budding-flowering			Flowering-yellowing of the lower leaves			Irrigation rate (m^3/ha)
	Duration, (hour)	Irrigation rate (m^3/ha)	Number of waterings	Duration, (hour)	Irrigation rate, (m^3/ha)	Number of waterings	Duration, (hour)	Irrigation rate (m^3/ha)	Number of waterings	Duration, (hour)	Irrigation rate (m^3/ha)	Number of waterings	
2020													
	1.5	110	5	1.5	110	8	1.0	73	2	1.0	73	20	3036
Irrigation rate for the period, (m^3/ha)		550			880			146			1460		
Date		15.04-09.05			10.05-09.06			10.06-14.06			15.06-18.07		
Number of days of the period		25			31			5			34		
2021													
	3	200	2	2	150	5	1.5	100	1	3	200	5	2250
Irrigation rate for the period, (m^3/ha)		400			750			100			1000		
Date		24.04-17.05			18.05-21.06			22.06-26.06			27.06-21.07		
Number of days of the period		24			35			5			25		

Yield is an integrated indicator of the elements of the crop structure (the number of tubers per plant, the average weight of one tuber and the density of standing) (Rubin, 1967). In our experiments, the density of standing was 45 thousand plants per hectare. Therefore, the tuberous productivity and the size of tubers were a direct indicator of the effectiveness of potato cultivation with the drip irrigation method in our experiments. The commercial and economic value of the variety was determined by the yield of tubers of large and medium fractions and the seed value was determined by the number of tubers of medium fractions. Maintaining soil moisture at the required level allowed us to obtain a high and high-quality potato crop. The yield averaged 40.6 t/ha in 2020 and 41.2 t/ha in 2021.

Analysis of literary sources on the problem under study showed that the past and expected future climate changes have an impact on its extremity. There is a tendency for climate warming, intra-annual precipitation changes (Edelgeriev, 2019; Lysenko, 2019; Peterson, 2005). In the conditions of agricultural production among hydrome teorological phenomena the recurrence, duration and area of atmospheric droughts are of particular danger (Perevedentsev *et al*., 2012; Yang *et al*., 2020; Zolotokrylin *et al*., 2020). Scientists offer various criteria for identifying droughts, such as precipitation during the growing season, relative air humidity, productive moisture reserves in the soil, reduced crop yields and others (Balakai *et al*., 2020, Olgarenko *et al*., 2018; Ruban and Yashalova, 2017). The indicator that characterizes the moisture availability of the territory is the hydrothermal coefficient of moisture G.T. Selyaninov (HCT), which is the ratio of the amount of precipitation for a period of at least one month to the sum of temperatures above 10°C for the same period, reduced by 10 times. (Borodychev and Lytov, 2019; Ionova *et al*., 2019; Chen and Jeong, 2018; Yuferev and Tkachenko, 2021). In the conditions of the dry-steppe zone of the Volgograd region, the cultivation of vegetable crops without irrigation is practically impossible. The Application of resource-saving technologies in irrigation, such as drip irrigation, is becoming more and more demanded. Consequently, the study of indicators of drought intensity impact on irrigation regime and total water consumption of vegetable crops remains relevant. This allows for analyzing the emerging climatic conditions to forecast and calculate the irrigation rates to obtain the planned yields.

CONCLUSION

As a result of the obtained studies, it was found that depending on the indicators of the intensity of drought during the growing season, the irrigation regime of crops changes. Taking into account the indicators of heat and moisture availability for individual months of vegetation in the calculation of water consumption of irrigated areas allows you to obtain stable high yields. The hydrothermal coefficient for the growing seasons in the years of research was 0.9 and 0.8, respectively, which characterizes them as arid. At the same time, during the interphase vegetation period “sowing-sprouting” irrigation rate changed by 27%, during the period “sprouting-budding” -by 15%, “budding- flowering” and “flowering-yellowing of lower leaves”-by 32%. And as a consequence, 26% more irrigation water was required in 2020 than in 2021. Accounting of the HTC by periods (months) allowed to obtain high potato yields at the level of 40 t/ha at the cost of irrigation water in 2020 3036 m^3/ ha and in 2021 2250 m^3/ha.

ACKNOWLEDGEMENT

The work was carried out within the framework of the state task of the research work of the FSC of Agroecology RAS No. 122020100316-8 “Digital technologies for managing agroforestry systems based on mathematical modeling, dynamic characteristics of bioproductivity of forest belts and agrophytocenoses in a changing climate in southern Russia”.

Conflict of interest: None.

REFERENCES

Balakai, G.T., Selitsky, S.A., Dokuchaeva, L.M., Yurkova, R.E. (2020). Rostov region territory zoning on agro-climate subzones for perspective soy varieties of various maturity groups. Scientific Journal of Russian scientific Research Institute of Land Improvement Problems. 3(39): 52-67. DOI: 10.31774/2222-1816-2020-3-52-67.

Borodychev, V.V. and Lytov, M.N. (2019). Technical and technological bases of agrophytocenosis hydrothermal regime regulation under irrigation conditions. Scientific Life. 10(98): 1484-1495. DOI: 10.35679/1991-9476-2019-14-10-1484-1495.

Chen, X. and Jeong, S.J. (2018). Irrigation enhances local warming with greater nocturnal warming effects than daytime cooling effects. Environmental Research Letters. 13(2): 024005. DOI: 10.1088/1748-9326/aa9dea.

Edelgeriev, Ð.S.H. (2019). Global climate and soil cover in Russia: Desertification and land degradation, institutional, infrastructural, technological adaptation measures (agriculture and forestry). IBA Publishing House, Moscow, Russia. 476 p.

Federal State Statistics Service. (2020). A brief statistical collection 2021 Volgograd Region in numbers 2020. http://34.rosstat.gov.ru/storage/mediabank/whW83IA5/02_2020_31052021.pdf.

Haider, S. and Ullah, K. (2020). Projected crop water requirement over agro-climatically diversified region of Pakistan. Agricultural and Forest Meteorology.281:107824. DOI: 10.1016/j.agrformet.2019.107824.

Ionova, V.Å., Likhovidova, V.A., Lobunskaya, I.A. (2019). Drought and hydrothermal humidity factor as one of the criteria to estimate its intensity degree (Literature review). Grain Economy of Russia. 6(66): 18-22. DOI: 10.31367/2079-8725-2019-66-6-18-22.

Kireicheva, L.V. and Karpenko, N.P. (2015). Evaluation of the efficiency of irrigation in a zonal soil sequence. Eurasian Soil Science. 5: 587-596. DOI: 10.7868/S0032180X15030065.

Kleshchenko, A.D., Lebedeva, V.M., Goncharova, T.A., Naidina, T.A., Shklyaeva N.M. (2016). Estimation of drought-related yield loss using the dynamic statistical model of crop productivity forecasting. Russian Meteorology and Hydrology. 41(4): 299-306.

Kostyakov, A.N. (1960). Fundamentals of Land Reclamation: A Textbook for Universities. Ed. 6th. Selkhozgiz, Moscow, Russia. 622 p.

Litovchenko, À.I. (2011). Modern climate change and irrigation. Ways to improve efficiency of irrigated agriculture. Collection of Scientific Papers. 45: 162-170.

Lysenko, S.A. (2019). Climate-dependent changes in the bioproductivity of terrestrial ecosystems in Belarus. Izvestiya, Atmospheric and Oceanic Physics. 6: 77-88. DOI: 10.31857/S0205-96142019677-88.

Olgarenko, Â.I., Olgarenko, I.V., Olgarenko, V.Ig., Pankarikova, A.A., Efendiev, M.S., Kostunin, G.G. (2018). Rationing of crop water consumption taking into account the variability of hydrometeorological conditions. Scientific Journal of Russian Scientific Research Institute of Land Improvement Problems. 2(30): 22-40.

Olgarenko, Â.I. (2014). Differentiated irrigation and mineral nutrition regimes for summer planting period potatoes. Ways to Increase the Efficiency of Irrigated Agriculture. 52: 160-164.

Olgarenko, Â.I., Babichev, A.N., Monastyrsky, V.A. (2019). Water balance and irrigation regime for vegetable crops in the lower don flood plain. Scientific Journal of Russian Scientific Research Institute of Land Improvement Problems. 2(34): 1-16. DOI: 10.31774/2222-1816-2019-2-1-16.

Ovchinnikov, A.S., Bocharnikov, V.S., Meshcheryakov, M.P., Bocharnikova, O.V. (2017). Efficiency of irrigation water consumption when irrigating vegetable crops. 4(48): 46-52.

Ovchinnikov, A.S. and Filimonov, R.A. (2008). Drip irrigation regime and water consumption of potatoes on light-chestnut soils of Volga-Don interfluvial area. Proceedings of the Kuban State Agrarian University. 1: 58-63.

Ovchinnikov, À.S., Bocharnikov, V.S., Meshcheryakov, M.P., Bocharnikova, O.V. (2012). Water saving effect under drip and in-soil irrigation of vegetable crops. Land Reclamation and Water Use. 5: 16-18.

Ovchinnikov, À.S., Bocharnikov, V.S., Meshcheryakov, M.P., Bocharnikova, O.V., Loboyko, V.F. (2017). Technological schemes of ensuring the efficiency of drops and intracorous irrigation systems. Izvestia of the Lower Volga Agro-University Complex. 1(45): 170-175.

Perevedentsev, Yu.P., Sharipova, R.B., Vazhnova, N.A. (2012). Agroclimatic resources of Ulyanovsk region and their impact on grain yields. Bulletin of the Udmurt University. Series Biology. Science of Earth. 2: 120-126.

Peterson, T.C. (2005). Climate ñhange indices. WMO Bulletin. 54(2): 83-86.

Pleshakov, V.N. (1983). Methodology of field experiment under irrigation conditions. VNIIOZ, Volgograd, Russia. 148 p.

Ruban D.A. and Yashalova N.N. (2017). Danger of drought as a challenge for agriculture in russia under current economic conditions. National Interests: Priorities and Security. 2: 101-113.

Rubin, B.A. (1967). Physiology of Agricultural Plants: In 12 Volumes. Publisher MSU, Moscow, Russia. 371 p.

Rusiva, Z.M. (1967). Agroclimatic handbook for the Volgograd region. Hydrometeoizdat, Leningrad, Russia. 144 p.

Vedeneeva, V.A. and Ruleva, O.V. (2021). Optimization of calculated doses of mineral fertilizers for the planned yield of potatoes in the conditions of Sredneakhtubinskiy district of Volgograd region. Agrochemical Herald. 4: 29-34. DOI: 10.24412/1029-2551-2021-4-006.

Yang, Q., Huang, X., Tang, Q. (2020). Irrigation cooling effect on land surface temperature across China based on satellite observations. Science of the Total Environment. 705: 135984. DOI: 10.1016/j.scitotenv.2019.1359841.

Yuferev, V.G. and Tkachenko, N.A. (2021). Dynamics of precipitation and temperature in the summer period on the territory of the volgograd trans-volga region. Izvestia of the Lower Volga Agro-University Complex. 2(62): 467-474. DOI: 10.32786/2071-9485-2021-02-46.

Zolotokrylin, A.N., Cherenkova, E.A., Titkova, T.B. (2020). Aridization of arid lands of the European part of Russia and connection with droughts. Izvestiya Rossiiskoi Akademii Nauk. Seriya Geograficheskaya. 2: 207-217. DOI: 10.31857/S2587 55662002017X.

Zwolinski, V.P. and Bondarenko, A.N. (2015). Problems of rational nature management in the Lower Volga ecoregion. Izvestia of the Lower Volga Agro-University Complex. 1(37): 13-18.