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Abbasov G.I. summarized the material and wrote the manuscript. Abbasov G.I. has exclusive author's rights and bear equal responsibility for plagiarism.

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The author declares no conflict of interests regarding the publication of this paper.

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НОВЫЕ НАПРАВЛЕНИЯ СОВЕРШЕНСТВОВАНИЯ ВОДООБОРОТНЫХ СИСТЕМ В МЕЛИОРАЦИИ

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Для получения высоких и устойчивых урожаев на мелиорированных землях требуется систематическое внесение минеральных удобрений для возмещения элементов питания, выносимых с урожаем. Наиболее эффективным способом предотвращения выноса элементов минерального питания за пределы осушаемых территорий является строительство водооборотных систем. Рассмотрены две водооборотные осушительно-увлажнительные системы, защищенные патентами РФ на изобретения. Первая – осушительно-увлажнительная система, включающая закрытые дрены, сопряженные с коллекторами, оборудованными колодцами-накопителями дренажного стока, к которым подключены установки мелкодисперсного дождевания. Вторая – водооборотная осушительно-увлажнительная система, включающая в себя дренажный коллектор, дренажный колодец, дрены, комплекс вертикальных колодцев-накопителей, неразряжающиеся сифоны и насос. Предлагаемые системы позволяют собирать и накапливать дренажные воды в период их избыточного скопления на осушаемом участке летом, а при возникновении дефицита влажности в корнеобитаемом слое почвы использовать накопленную воду для проведения орошения способом субирригации без строительства дополнительной оросительной сети. Отмечено, что описанная система колодцев-накопителей может служить водоисточником как для системы мелкодисперсного дождевания, так и для системы капельного орошения, так как вода, накопленная в колодцахнакопителях, не содержит биофитов и крупных взвешенных частиц и не требует очистки на специальных фильтрах. Применение новых способов орошения позволяет предотвратить не только вынос с дренажной водой удобрений, но и обеспечить влагой сельскохозяйственные культуры во время кратковременных засух.

Ключевые слова: вынос удобрений с дренажным стоком, водооборотные мелиоративные системы, мелкодисперсное дождевание на осушенных землях, внутрипочвенное орошение на осушенных землях, способы накопления дренажного стока.

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NEW DIRECTIONS FOR IMPROVING WATER CIRCULATION SYSTEMS IN IRRIGATION

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To obtain high and sustainable yields on reclaimed land, systematic application of mineral fertilizers is required to replace the nutrients removed with the crops. The most effective way to prevent the removal of elements of mineral nutrition outside the drained areas is the construction of water circulation systems. The paper considers two water circulating drainage-and-moistening systems protected by the Russian Federation patents for inventions. The first one is a drainage-and-moistening system, which includes closed drains associated with collectors equipped with drainage drain storage wells, to which fine sprinkler systems are connected. The second is a water circulation drainage-and-moistening system, which includes a drainage collector, a drainage well, drains, a set of vertical storage wells, non-diverging siphons and a pump. The proposed systems allow collecting and accumulating drainage water during the period of their excessive accumulation in the drained area in summer, and using accumulated water in the periods of a soil moisture deficit in the root zone to irrigate the soil be means a sub-irrigation method without constructing an additional irrigation network. It is noted that the described system of storage wells can serve as a water source for both the fine sprinkling system and the drip irrigation system, since the water accumulated in the storage wells does not contain biofits and large suspended particles and does not require cleaning with special filters. The use of new irrigation methods prevents not only the fertilizer removal with drainage water, but also supplies crops with moisture during short-term droughts.

Key words: removal of fertilizers with drainage runoff, water-circulating reclamation systems, fine sprinkling on drained lands, internal soil irrigation on drained lands, methods of accumulating drainage runoff.

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Introduction. Crop growing in irrigated areas should take into account environmental requirements for the irrigation system, in particular, it is necessary to prevent the removal of mineral elements by drainage waters into a catch-water. Thus, according to Volga Region Research Institute of Ecological Reclamation Technologies, when calculating fertilizer application rates for planned harvest on the irrigated land of the Volga region, environment safety standards should be varied depending on the cultivated crop and expected yield. At the planed yield of alfalfa hay of 12…16 tons/ha, an environmentally safe application rate of fertilizers will be *N*60*P*120*K*90. For corn grain with a yield of 8…10 tons/ha, an environmentally safe rate will be *N*160*P*120*K*85. For a planned potato yield of 25…35 t/ha, this indicator will constitute *N*90*P*110*K*110 [1].

The research purpose is to identify trends in the development of drainage water recycling on drainage and moistening systems, to assess the possibility of using drainage water, ways of its accumulation and rational use, to determine the influence of fertilizer rates on the flow of mineral elements into drainage water.

Material and methods. The authors have used materials of theoretical and experimental studies on the recycling of drainage water, as well as a system analysis and a regulatory method.

Results and discussion. On drained peatlands of the Yahroma floodplain, carrots were fertilized at the *N*100-200*P*100*K*140-180 rate. For cabbage, fertilization standards amounted to *N*140-180*P*140*K*230-250. 80% of the rate was applied during spring tillage and 20% –

in top-dressing. With such application rates, annual average removal of minerals by the drainage waters amounted to 12.20 kg/ha of nitrogen, 0.23 kg/ha of phosphorus, and 11.90 kg/ha of potassium [2].

Granulometric composition of the soil has a significant impact on the removal of mineral elements from irrigated fields. In the experiments carried out on "Prigorodnoye" experimental farm in the Kirov region on the fields with sandy and loamy soil composition, where fertilizers were systematically applied in high rates, an increased content of mineral elements was observed in drainage water. In the experiments on a plot with a closed tile drainage laid every 20 meters at a depth of 1.0…1.1 m, with a fertilizer application rate under potato being *N*100-90*P*100-120*K*100-120, an increase of the nitrate concentration in the drainage water was observed. It was 1.2…1.5 times higher as compared with a control plot without fertilizer application. While the nitrate content on the control plot was 42 mg/liter, in version with fertilizer application it reached 73.7 mg/liter. The concentration of potassium in the drainage water was 1.9…5.0 mg/l for both plots. The concentration of chloride in the drainage water for the case with application of fertilizers increased in 1.3-1.8 times from 16.2 to 28.9 mg/liter due to the presence of fertilizers it in. The highest concentration of nitrate in drainage water – 76.9 mg/l was observed in spring after thawing of the upper soil layer. It should be noted that 42% of average annual runoff of 151 mm occurs during the spring season [3].

During summer drought there may be different options of bilateral regulation of the soil irrigation mode. First of all, this can be done by supplying water through the capillaries from the groundwater level by a floodgate method. In this case, the level of groundwater should be held not below the drainage requirements. With a lower level of groundwater, soil moisture level is supported by traditional surface irrigation. Drainage water kept in reservoirs can serve as a water source [4].

In connection with the negative consequences of fertilizer-contaminated drainage flow coming into the water reservoir, as well as its losing a significant number of mineral elements, it was necessary to use drainage-irrigation water circulation systems.

I.V. Minayev and A.M. Voitovich [5] systematized irrigational water circulation systems basing on the way of accumulating drainage water. The authors have identified a large group of systems accumulating drainage runoff in ponds. One separate group included systems with vertical drainage. Another group comprised water circulation systems with ground reservoir.

Special role belongs to a system of collector wells. In these systems, drainage network in the field is complemented by wells with radial accumulators made out of large-diameter pipes. In spring time, wells and radial pipe accumulators are filled with water, which is used for irrigation during the summer in the period of low soil humidity. Collectors and drains in porous filling placed in the tray made of polymer film are also used as drainage water accumulators. This collector-drainage system is able to save the amount of water sufficient for one watering operation at a rate of 300 m^3/ha. [5]

The system with radial collector wells was tested on the fields of experimental farm "BelNIIMiVKHa". Water from the well with radial accumulators was consumed with a "ДДН-70" installation. The accumulated water volume amounted to 68 m^3. This water amount is sufficient for irrigating 0.28 ha area for 15 minutes. The estimated irrigation rate was 240 m^3/ha. Thanks to a constant drainage water inflow, four irrigation operations were performed during the vegetation period, in which 240 m^3/ha of water were consumed. Thus, the estimated irrigation rate was 800 m^3/ha.

As per ha, 0.59 kg of nitrogen, 5.89 kg of potassium and 48.7 kg of organic matter was introduced in the field with drainage water. The first experiments have shown that the typical sprinkling nozzle "ДДН-70" with 55 mm-diameter provides too high intensity of water spraying, which leads to the formation of puddles and surface water runoff. In addition, because of high-speed water pumping, the air entered in the suction tube of the pump and the vacuum was broken. Reducing the sprinkler nozzle size to 16 mm and installing a fitting for the release of air on the suction tube allowed to reduce the intensity of water sprinkling, to improve the irrigation quality and to provide a normal mode of water pick up from the collector well.

Wells with radial accumulators in the form of tile drains inserted into porous filling were tested on the same farm. The volume of water accumulated in such well was 65 m^3. Pumping speed was significantly lower and the watering intensity lowered as well. Two irrigation operations were carried out. The first watering operation was made at a rate of 47.8 m^3 on an area of 0.44 ha and the second was made at a rate of 41 m^3 on an area of 0.64 ha; thus, the irrigation rate was 172 m^3/ha.

Notably, even if the drainage system was supplied with special devices for the accumulation of drainage runoff, stored water was sufficient only for a few watering operations performed with traditional methods. This allows only to prevent a sharp decrease in crop yields in average water-deficient years. Therefore, more rational use of accumulated drainage water based on a low-volume irrigation technology is rather promising.

One of the trends of low-volume irrigation is fine sprinkling. Experiments on daily fine sprinkling of potato crops were conducted with the help of the "ОП-450" system. After one vegetative sprinkling in the middle of June with "ДДА-100" at a rate of 250 m^3/ha, the plot was irrigated with the "ОП-450" system at a rate of 4,6 m^3/ha for 51 days, when the air temperature on the field exceeded 22°C in the hottest hours of the day. Spraying was made several times with one-hour intervals. 237 m^3/ha of water was consumed for the 51-day period. Taking into account one traditional irrigation in June, the irrigation rate accounted for 487 m^3/ha. Crop yield in experimental version was 405.7 centners/ha. The control plot was watered with the help of the "ДДА-100" installation. 7 watering operations were performed at a rate of 3620 m^3/ha. Potato crop yield from the control plot amounted to 289 centners/ha. Thus, the crop increase with a dramatic reduction of irrigation rates accounted for 117 centners/ha or approximately 40% [6].

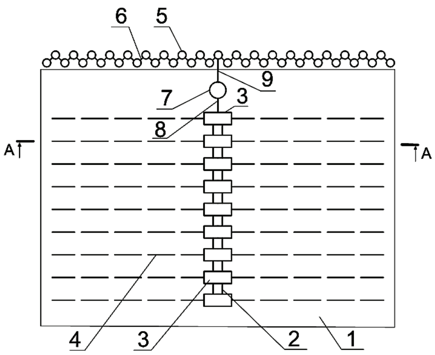
The results of these studies show that with the use of fine irrigation in the conditions of the Non-Chernozem zone, the amount of water accumulated in the system with collector wells is enough to maintain a favorable level of soil moisture throughout the drought period without resorting to additional water sources.

For the implementation of this technology VNIIGiM proposed a drainage-irrigation system that consists of closed drains adjoined with collectors, which are equipped with collector wells for drainage runoff, to which fine sprinkling devices are connected. Each such device has a power unit, a water pump, a compressor with adjustable air supply and a mixing chamber with a discharge cap. The compressor is connected to the mixing chamber entry. The water pump conjugates with nozzles installed at the mixing chamber output. The cap can rotate horizontally and is equipped with two diametrically located sprinkling nozzles curved in opposite directions. Use of the compressor in combination with supplying water through the nozzles provides its dispersion in an aerosol form. This aerosol is thrown over the surface of the field through the nozzles rotating at a given speed that allows to ensure that the water supply intensity is non-destructive for soil and does not form any runoff [7].

In hilly terrains that are characteristic for the Non-Chernozem zone, there occur saucer-type lowered areas (bolsoms) formed on low water permeable soils, which are common within a drained massif. In these places, there is constant soil waterlogging that prevents timely performance of farm operations. As a rule, the drainage of such sites is technologically difficult and not economically feasible.

The main feature of closed waterlogged sites without suitable conditions for the removal of excess moisture is the availability of an underlying soil layer with low water permeability and the lack of an available catch-water. To solve problems in such areas, VNIIGiM suggested using a water circulation drainage-irrigation system that provides for the accumulation of drainage water and its subsequent use. Subirrigation helps maintain a soil moisture level that is favorable for plants without off-site water diversion [8].

Figure provides a scheme of water circulation drainage-irrigation system, which allows to accumulate and use the drainage water within the drained site. This system uses a complex of vertical collector wells for the accumulation of both surface runoff and drainage water.



A water circulation drainage-irrigation system:
1 – drained plot; 2 – drain collector; 3 – drain well,
4 – drains; 5 – collector wells; 6 – non-discharging siphons;
7 – pump; 8 – water intake pipe; 9 – delivery pipe

Водооборотная осушительно-увлажнительная система:
1 – осушенный участок; 2 – дренажный коллектор;
3 – дренажный колодец; 4 – дрены;
5 – колодцы-накопители; 6 – неразряжающиеся сифоны;
7 – насос; 8 – водозаборный трубопровод насоса;
9 – нагнетательный трубопровод насоса

To maintain a water-air soil mode that is favorable for crops, a drainage network is installed on plot *1*, which includes drain collector *2* with drainage wells *3*, in which drains *4* are connected to the collector. These drains are installed with zero slope in relation to the collector. The distance between drains is 10…15 meters. Above the plot a structure is installed on the slope to replace the upland channel. This construction consists of several series of vertical waterproof collector wells *5* connected with one another by non-discharging siphons *6*. At the top part of these wells, above the placement of drains, a perforation protected by a polymer filter is made. Installed at the beginning of drainage collector *2* is pump *7*. Water intake pipe *8* of this pump is equipped with a water distributing junction consisting of the pipe connected to collector well *5*, as well as the pipe placed in drain well *3*. Delivery pipe *9* of pump *8* is equipped with a water distributing junction consisting of a pipe connected to drain well *3*, and a pipe connected to collector well *5*. Siphons *6* are connected to the pipe communicating with a vacuum pump. The drainage placement depth is determined by the capacity of an upper sandy or loamy layer underlain with a water resistant layer, and in case of significant thickness of the upper layer – by the predetermined drainage depth.

The water circulation drainage-irrigation system operates in the following way:

During spring snow-melting, meltwater seeps through well perforation *5*. After wells *5* are filled with water to the lower level of all siphons *6*, discharge is produced with the help of a vacuum pump and siphons *6* are filled with water. The design of non-dischargeable siphons *6* is characterized by upward bend of the end sections of both branches and their location on the same level. After siphon charging, the water level in all collector wells *5* is equalized due to the water flow from one well into the other through siphons. Water seeps from the thickness of the drained layer into drain *4*, and then into collector *2*. Water from drainage well *3* is moved by pump *8* into collector well *5*, and then flows in nearby collector wells *5* though non-dischargeable siphons *6*. The number of wells and their volume is determined basing on the calculation of the runoff amount formed on the drained area. After the groundwater level is reduced to the norm, drainage pump *8* is cut off.

In summer, when water reserve on plot *1* is spent on evapotranspiration of the cultivated crop root zone, soil moisture level is reduced to 60…65% of maximum water retention. In this case, there is a need for additional soil irrigation in the root zone. For that purpose, pump *8* takes water from collector well *5* and sends it through drain well *3* into collector *2*, from which it comes into drain *4*, and then in the surrounding soil. In this case the moisturizing of root zone is performed by the subirrigation method. A small distance between drains *4* and the lack of the slope provides uniform moisturizing of the plot area, and water storage in closed wells prevents the reproduction of algae and contamination of the drain perforation. In the process of picking up water from the first collector well, it is constantly refilled from the neighboring wells through siphons *6*, and they are also refilled from the neighboring wells. Thus, equal level of water is maintained in all the wells. After the desired level of soil moisture is reached, the flow of water into collector *2* is stopped.

In the case of heavy summer rainfall, excessive moisture above the set drainage standards can be observed. In this case, pump *8* is switched to work in pumping from drainage well *3* and filling collector wells *5*.

Thus, the proposed system allows to collect and store drainage water in the period of its excess on the drained plot in summer, and to use the accumulated water by the subirrigation method when needed without the construction of an additional irrigation network.

It should be noted that the described system of collector wells can serve as a water source for both the fine sprinkling system and the drip irrigation system, since the water stored in collector wells does not contain biofits or large suspended particles and does not require cleaning with special filters.

Conclusions

1. To obtain high and sustainable crop yields on reclaimed lands, systematic application of mineral fertilizers is required for the reimbursement of nutrients removed with farm produce at the harvest time. Part of fertilizers is removed with drainage runoff to water reservoirs, thus causing their pollution.

2. The most effective way to prevent the removal of the mineral elements from the drained areas is the construction of water circulation systems. These systems provide an opportunity to collect and keep drainage water for later use for crop irrigation during summer drought periods.

3. Use of “ДДН-70” “ДДА-100” systems does not allow fully recovering of moisture deficit in a dry period. The accumulated drainage water can be used in the most effective way by means of modern low-volume irrigation methods.

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Contribution

Shevchenko V.A., Gubin V.K., Kudryavtzeva L.V. summarized the material and wrote the manuscript. Shevchenko V.A., Gubin V.K., Kudryavtzeva L.V. have equal author’s rights and bear equal responsibility for plagiarism.

Conflict of interests

The authors declare no conflict of interests regarding the publication of this paper.

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