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**Критерии авторства**

Кирсанов В.В., Павкин Д.Ю., Никитин Е.А., Юрочка С.С. выполнили теоретические исследования, на основании которых провели обобщение и написали рукопись. Кирсанов В.В., Павкин Д.Ю., Никитин Е.А., Юрочка С.С. имеют на статью авторские права и несут ответственность за плагиат.

**Конфликт интересов**

Авторы заявляют об отсутствии конфликта интересов.

**Статья поступила 23.06.2020**

**Опубликована 30.10.2020**

**Contribution**

V.V. Kirsanov, D. Yu. Pavkin, Ye.A. Nikitin, S.S. Yurochka carried out theoretical studies, generalized the obtained results and wrote the manuscript. V.V. Kirsanov, D. Yu. Pavkin, Ye.A. Nikitin, S.S. Yurochka 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.

**The paper was received on June 23, 2020**

**Published 30.10.2020**

**ТЕХНИКА И ТЕХНОЛОГИИ АПК / FARM MACHINERY AND TECHNOLOGIES**
**ОРИГИНАЛЬНАЯ СТАТЬЯ / ORIGINAL PAPER**
**УДК 631.6:626.86**
**DOI: 10.26897/2687-1149-2020-5-32-37**

# НОВЫЕ ТЕХНИЧЕСКИЕ РЕШЕНИЯ В РАЗРАБОТКЕ ОСУШИТЕЛЬНО-УВЛАЖНИТЕЛЬНЫХ СИСТЕМ ДЛЯ УСЛОВИЙ НЕЧЕРНОЗЕМНОЙ ЗОНЫ РФ

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Рассматриваются проблемы совершенствования конструкций осушительно-увлажнительных систем в Нечерноземной зоне с учетом большого разнообразия в ней природно-климатических и мелиоративных условий. Предлагается рассматривать направления разработки новых технических решений, исходя из разделения зон на мелиоративные подзоны: средне-таежную, южно-таежную, лиственно-лесную и лесостепную. В средне-таежной подзоне, где сумма осадков превышает испаряемость, основным направлением является разработка способов ускоренного отведения избытков влаги, улучшения теплового режима почвы и поддержания уровня грунтовых вод в пределах нормы осушения. В южно-таежной зоне, где сумма осадков в среднем соответствует испаряемости, но наблюдается чередование засушливых лет с годами, когда наблюдается избыточное выпадение осадков именно в период формирования урожая, необходимо совершенствовать осушительно-увлажнительные системы с расширением их функциональных возможностей в части экономного использования осадков, накопления дренажных вод и снижения оросительных и поливных норм путем применения малообъемных способов орошения, а также регулирования водно-воздушного режима почвы и приземного слоя воздуха. В лиственно-лесной и лесостепной зонах следует отдать преимущество разработке осушительно-увлажнительных систем со стационарными системами увлажнения и рециклингом дренажных вод на основе новых конструкций для их накопления, а также применению усовершенствованных дождевальных систем, капельного орошения и мелкодисперсного дождевания.

**Ключевые слова:** осушительно-увлажнительные системы, избыточная влага, дренажные воды, конструкции дождевателей, капельное орошение.

**Формат цитирования:** Шевченко В.А., Губин В.К., Кудрявцева Л.В., Алипичев А.Ю. Новые технические решения в разработке осушительно-увлажнительных систем для условий Нечерноземной зоны РФ // Агроинженерия. 2020. № 5(99). С. 32-37. DOI: 10.26897/2687-1149-2020-5-32-37.

# NEW TECHNICAL SOLUTIONS FOR THE DEVELOPMENT OF DRAINAGE-IRRIGATION SYSTEMS FOR NON-CHERNOZEM ZONE OF RUSSIA

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The paper discusses the problems of further improving the design of drainage and irrigation systems in the Non-Chernozem zone, taking into account the great variety of its natural-climatic and reclamation conditions. The authors propose some new ways of developing advanced technical solutions based on the division of the zone into reclamation subzones: mid-taiga, south-taiga, deciduous-forest and forest-steppe ones. In the mid-taiga subzone, where the amount of precipitation exceeds that of evaporation, the main trend is the development of methods for accelerated diversion of excess moisture, improving the thermal regime of the soil and maintaining the groundwater level within the drainage limits. In the south-taiga zone, the amount of precipitation on average corresponds to that of evaporation, but years with excessive moisture tend to alternate with the years characterized with insufficient moisture. During the crop formation, it is necessary to improve the drainage and irrigation systems in order to expand their functional capabilities in terms of the economical use of precipitation, the accumulation of drainage water and the reduction of irrigation rates by applying low-volume irrigation methods, as well as regulating the water-air regime of the soil and the surface air layer. In deciduous-forest and forest-steppe zones, preference should be given to the development of stationary irrigation systems and recycling of drainage water, based on new designs for its accumulation, as well as to the use of advanced irrigation systems, drip irrigation and micro sprinklers.

**Key words:** combined (double-action) irrigation systems, excess moisture, drainage water, sprinkler designs, drip irrigation.

**For citation:** Shevchenko V.A., Gubin V.K., Kudryavtseva L.V., Alipichev A.Yu. New technical solutions for the development of drainage-irrigation systems for Non-Chernozem zone of Russia. Agricultural Engineering, 2020; 5 (99): 32-37. (In Eng.). DOI: 10.26897/2687-1149-2020-5-32-37.

**Introduction**: The Non-Chernozem zone of the Russian Federation is characterized by a large variety of topography, soil composition and fertility, hydrological regime, sum of active temperatures, amount of precipitation, evaporation, and farmland productivity [1].

In accordance with reclamation zoning, it is divided into several reclamation subzones: mid-taiga (57.8 million ha), south-taiga (98.3 million ha), deciduous-forest and forest-steppe (28.0 million ha) ones [2]. For the Northwestern and Central Federal Districts of the Non-Chernozem zone (the mid-taiga reclamation subzone), the main factor affecting crop yields is high soil moisture content due to the predominance of precipitation over evaporation. Unstable moisture content is characteristic of the south-taiga subzone, and moderately insufficient moisture content is characteristic of the deciduous-forest and forest-steppe subzones.

In the mid-taiga subzone, the amount of precipitation is 600…700 mm with an evaporation value of 350…450 mm and the runoff coefficient is 0.35…0.50. The probability of excessively wet years in this subzone is 30…40%, and that od dry years – 10%. Under these conditions, the improvement of drainage-irrigation systems should focus on the development of accelerated surface water diversion with their preliminary purification before its releasing into the water reservoir; automatic regulation of the groundwater level according to a given drainage rate; increasing the temperature of the arable layer to provide for an earlier start of sowing and stimulate the growth and development of cultivated crops.

The invention protected by the patent of the Russian Federation No. 2714837 "Drainage well-absorber for the intake and removal of surface water" aims at solving this problem. The well prevents the accumulation of flood and storm water in low spots of drained areas [3]. According to another patent of the Russian Federation No. 2655959 "Method of pumping surface water into the ground" in a drained area, vertical wells are drilled through a layer of waterproof soil to drain surface water into aquifers. A specific design feature of such wells is their form of a block of four interconnected vertical holes connected to neighboring wells by horizontal drains. Each well is equipped with a head made of filter material, which prevents the pollution of groundwater [4].

The accelerated surface water diversion is provided by the "Method of making ridges on drained lands" (RF patent No. 2706952). This method consists in making ridges and slits across the drains with the addition of copper pyrites into the soil above the drains, which, interacting with iron salts, reduces the risk of iron hydroxide depositing in the perforation of drainage pipes [5]. The "Method of slitting drained lands" (RF patent No. 2584444) can be applied in a similar way. According to this method, calcium carbonate is introduced into slits made across drains, which converts iron salts into an insoluble form and thereby reduces the iron hydroxide deposits in drains [6].

Irrigation of reclaimed land in this zone is ensured by maintaining a given drainage rate using various structures. For example, use can be made of retaining structures, i.e. check locks, on open drainage collectors. There are two methods of irrigational locking. The first one is continuous that ensures the maintenance of the groundwater level in accordance with the drainage rate. The other one is periodic, which raises the groundwater level in several times by closing locks [7]. To maintain a given drainage rate in a section with closed drains discharged into an open collector, a reclamation system that provides automatic control of maintaining a given drainage level in each separate drain has been developed (RF patent No. 2608052). According to this proposal, control devices are mounted on the heads of closed drains discharged into an open drainage collector in special chambers arranged in the collector. These devices are made in the form of a waterproof pipe section fixed at the end of the drain and connected by a flexible insert with a movable pipe, which is connected through a system of blocks with a cable to a float located in the collector. In a low-water period, when the outflow of drainage water from drains to the collector is stabilized, its level decreases. In this case, the float is lowered, and the wire-connected pipe goes up. The intensity of the water outflow is determined by the position of the outlet end of the nozzle above the drain outfall [8].

A schematic design of this device is shown in Fig. 1.

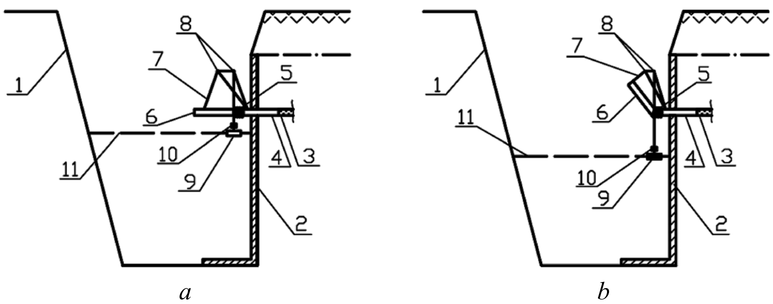


**Fig. 1. Device for regulating the groundwater level in the irrigation-drainage system**:
a) when diverting excess drainage water; b) at a decreased discharge of drainage flow and a stable pre-set level of groundwater;
1 – a drainage collector; 2 – a chamber on the drain head; 3 – a drain; 4 – a waterproof pipe section; 5 – a flexible insert;
6 – a pipe; 7 – a cable; 8 – blocks; 9 – a float; 10 – a mechanism for regulating the cable length; 11 – a water level in the reservoir

**Рис. 1. Устройство регулирования уровня грунтовых вод в оросительно-дренажной системе:**
a) при отводе лишних дренажных вод;
b) при уменьшении сброса дренажного стока и поддержании заданного уровня грунтовых вод;
1 – дренажный коллектор; 2 – камера на головке слива; 3 – слив; 4 – участок водонепроницаемой трубы;
5 – гибкая вставка; 6 – труба; 7 – трос; 8 – блоки; 9 – поплавок; 10 – механизм регулирования длины троса;
11 – уровень воды в резервуаре

On drainage systems, where the drains are connected to a closed collector, various designs of retaining devices are used. These devices are located in drainage wells, at the interface between the drain and the collector and regulate the water outflow from the drain (RF patent No. 2679690) [9]. Structures regulating the outflow of drainage water can also be mounted on the collector itself (patent No. 2668678) [10].

To accelerate soil heating in conditions of the mid-taiga subzone, use can be made of a solar heater for the subsoil layer when there is a high level of groundwater standing – RF patent No. 271657. The core idea of this proposal is to lay two ventilation pipes below the arable layer. It is important to note that one pipe is airtight and placed inside the air permeable second pipe. The ends of both pipes are brought to the surface and connected to solar air heaters [11].

In the South-taiga subzone, the amount of precipitation is 650…750 mm with an evaporation rate of 400…450 mm, a runoff coefficient of app. 0.25…0.40, and a humidification index of 0.45…0.60. This subzone is characterized by an unstable moisture level. Under these conditions, additional irrigation is necessarily required to obtain a high sustainable crop yield. In this environment, devices that support a given level of drainage by regulating the flow of water from each individual drain can be used. In this case, an economic rationale for the feasibility of building a stationary irrigation network should be provided. It is preferable to develop mobile irrigation systems. The development of such systems may be based on the use of drip irrigation and fine sprinkling systems. For irrigation of drained lands using mobile irrigation equipment, a drainage and irrigation system was proposed (RF patent No. 2628341) [12]. This system includes closed drains connected with collectors of well-equipped drainage flow accumulators during the spring flood period. In the dry period, these irrigation wells are connected to fine sprinkling systems located on special platforms. Each system has a power unit, a water pump, a compressor, an air supply regulator and a mixing chamber with a discharge nose. The discharge nose is mounted to rotate in the horizontal plane and is equipped with two diametrically located spray nozzles, curved in opposite directions, and capable of operating according to the Segner wheel rule. The air supply from the compressor in combination with the water injection through the nozzles provide aerosol formation. This aerosol is ejected above the field surface through nozzles rotating at a given speed, which ensures the intensity of water supply using a flow that does not destroy the soil and does not form a runoff.

The South-taiga subzone is characterized by the diversity in the relief and topsoil, as both low places with heavy flooded soils and elevated areas with sandy permeable soils can be found there. For low parts of the area, where groundwater diversion is difficult, an "Installation for growing fruit trees on lands with a high level of groundwater" has been designed (RF patent No. 2677307) [13]. This installation is shown in Fig. 2.

This technical solution is based on the idea that the plant is placed in a trellised container reinforced with a semipermeable membrane. The bottom of the container is equipped with special tubes with wicks connected to groundwater, providing an adjustable supply of water to the plant roots.

A method of drip irrigation has been developed for growing trees on sandy soils (RF patent No. 2653548). When planting trees, according to this method, holes are excavated to a depth of 1 m. A screen is formed at the bottom of the pit, laying a mixture of swelling clay (for example, that containing montmorillonite) with segments of polymer tubes, 1…3 mm in diameter and 4…10 cm long. The volume of the tubes is 30…40% of the clay volume, which corresponds to the average porosity of loamy soil. The thickness of the screen formed from the stacked mixture is 3…7 cm. After laying the screen, the hole is filled with soil removed during excavation of the pit. The seedling root ball is placed in the central part of the hole and covered with soil. A drip irrigation system is used for watering. In soils with high water permeability, water moves far down and capillary transfer to the sides of the dripper is 10…15 cm. Therefore, the largest amount of it will penetrate below the root layer of the soil to the screen. Wherein, the clay, that is part of the screen, will compress the section of the tubes, while absorbing moisture and swelling. As a result, the screen will lose its water permeability and irrigation water will linger on its surface, and then begin to move along the soil capillaries to the sides of the screen. After using the supplied moisture amount, the clay loses water, the compression of the tubes stops and the screen permeability is restored. This prevents the flooding of the root system and allows the roots to use nourishing elements trapped on the screen surface [14].

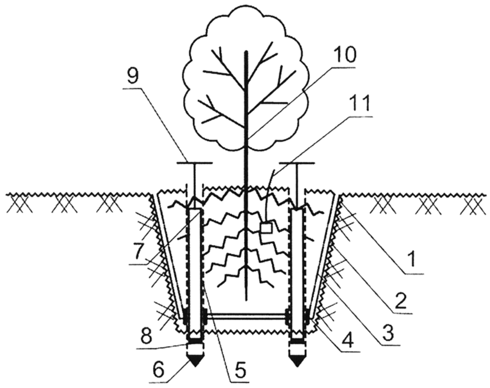


**Fig. 2. Installation for growing trees on lands with high groundwater levels:**
1– a planting hole; 2 – a perforated container;
3 – membrane material; 4 – a sealing ring in the container bottom;
5 – a perforated pipe; 6 – a conical plug;
7 – a container with a hygroscopic filler;
8 – a cork in the container bottom; 9 – a container handle;
10 – a tree seedling; 11 – a soil moisture sensor

**Рис. 2. Устройство для выращивания деревьев на почвах с высоким уровнем грунтовых вод:**
1 – посадочная яма; 2 – контейнер перфорированный;
3 – мембранный материал;
4 – уплотнительное кольцо в днище емкости;
5 – труба перфорированная; 6 – заглушка коническая;
7 – емкость с гигроскопичным наполнителем;
8 – пробка на дне емкости; 9 – ручка контейнера;
10 – саженец дерева; 11 – датчик влажности почвы

In the deciduous-forest and forest-steppe subzones, the sum of active temperatures is 2200…24000, the growing season lasts from 130 to 150 days, the amount of precipitation is 550…700 mm with an evaporation of 450…500 mm, the drain coefficient is 0.13…0.25. Thus, these subzones are characterized by a moderately insufficient moisture level, while the number of excessively wet years is 10%, and dry years account for 20…30%. It is advisable an additional stationary water distribution network should be built to supply water to both traditional sprinklers and advanced models that produce an irrigation effect of low rain intensity. An example of such an improved system is the "Irrigation Network" (RF patent No. 2620008). This technical solution includes a distribution network with stationary sprinklers with individual switching on. The operation of sprinklers is controlled remotely from a central computer. In this case, the computer receives information about the moisture consumption rate on the field in the real time mode from an unmanned aerial vehicle (UAV) [15]. A general view of this irrigation network is shown in Fig. 3.

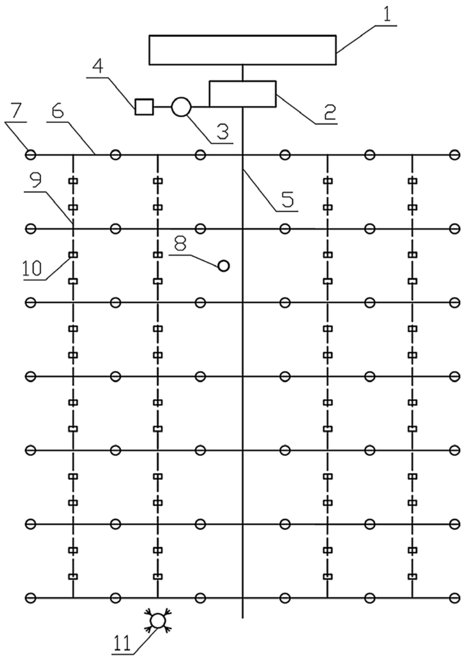


**Fig. 3. Irrigation network scheme:**
1 – a water source; 2 – a pumping station;
3 – a power source; 4 – a control unit with a central computer;
5 – a distribution pipeline; 6 – irrigation pipelines;
7 – sprinkler installations; 8 – a automated measuring system;
9 – travel paths of the quadcopter; 10 – evaporators;
11 – a quadcopter

**Рис. 3. Схема оросительной сети:**
1 – источник воды; 2 – насосная станция;
3 – источник питания; 4 – пункт управления с центральным компьютером;
5 – распределительный трубопровод;
6 – оросительные трубопроводы; 7 – спринклерные установки;
8 – автоматизированный измерительный комплекс;
9 – траектории движения квадрокоптера;
10 – испарители; 11 – квадрокоптер

The enhancement of drainage-irrigation systems should be focused on maintaining a favorable water-air regime both in the topsoil layer and the surface air layer. It should be possible to relieve the temperature stress during the hottest hours of the driest period through the use of fine or aerosol sprinkling. To obtain information about the state of crops in the real-time mode, UAVs can also be used [16].

Since irrigation water is often lacking in these subzones, the development of water circulation combined (double action) irrigation systems that accumulate drainage and then use it for irrigation is very important (RF patent No. 2655799). This water circulation system involves collecting all drainage and surface runoff into a system of vertical interconnected wells and, as the soil moisture decreases, supplying accumulated water to subsoil humidifiers [17].

Drip irrigation systems, in addition to maintaining a given moisture regime in the topsoil, can be used to control the soil temperature (RF patent No. 2685146). The technical solution protected by this patent is to combine drip irrigation with a screen made of a non-water permeable but air-permeable membrane film that will cover the soil plot with a row of plants. This makes it possible to maintain a favorable water-air regime in the potato tubers formation zone during hot weather and to divert rain water in case of excessive moisture [18]. The drip irrigation system can be used to enrich the surface layer of air with carbon dioxide (RF patent No. 2717648). This method implies that the pipe with drippers laid in the furrow between the rows of plants, is covered with a membrane film and after the end of watering, carbon dioxide is supplied through the dripper outlets, seeping through the film pores. It accumulates on its surface between plants and then is used by them to form organic matter in the process of photosynthesis [19].

**Conclusion:** Thus, the application of the above design solutions to regulate the water-air regime of the soil used for crop cultivation will provide for the effective use of the soil and climatic conditions of different reclamation subzones of the Non-Chernozem zone of Russia.

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**Критерии авторства**

Шевченко В.А., Губин В.К., Кудрявцева Л.В., Алипичев А.Ю. выполнили теоретические исследования, на основании которых провели обобщение и написали рукопись. Шевченко В.А., Губин В.К., Кудрявцева Л.В., Алипичев А.Ю. имеют на статью авторские права и несут ответственность за плагиат.

**Конфликт интересов**

Авторы заявляют об отсутствии конфликта интересов.

**Статья поступила 13.07.2020**

**Опубликована 30.10.2020**

**Contribution**

V.A. Shevchenko, V.K. Gubin, L.V. Kudryavtseva, A.Yu. Alipichev carried out theoretical studies, generalized the obtained results and wrote the manuscript. V.A. Shevchenko, V.K. Gubin, L.V. Kudryavtseva, A.Yu. Alipichev 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.

**The paper was received on July 13, 2020**

**Published 30.10.2020**