Effectiveness of drainage of agricultural land by closed drainage in climatic conditions of the Novgorod Region

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Abstract. The objects of this study are closed drainage systems having a hydraulic connection of arable horizon with a drainage pipe. Experimental plots are located in the Novgorod region on sod-podzolic loamy soil. In the experiment we used such kinds of design as a standard construction with filling the drainage trench with sand-gravel mixture to the arable horizon, and a construction in the form of two-tiered drainage. The distance between drains is 14 m, the depth is 1.1 m. The design of two-tiered drainage provides for the upper tier of cavity-free drains with a depth of 0.5 m, a distance between the drains 6 m, located perpendicular to the lower tier. As a result of the study of dynamics of groundwater and soil humidification, we found out that in the experimental systems of two-tiered drainage in excessively wet years, groundwater had not risen into the topsoil during the entire growing period. Formation of groundwater after heavy rainfall was more intensive in the two-tiered drainage systems. The most favorable water-air regime in the years with different precipitation conditions (both in dry and abnormally wet years) was provided by the experimental two-tiered drainage systems with a smaller amplitude of fluctuations in moisture reserves in a soil arable layer which allowed us to conclude that draining of collectors was more effective on the base of the two-tiered drainage.

1. Introduction
The Novgorod region belongs to the zone of unstable moistening, and in the conditions of heavy soils and flat topography often experiences excess moistening. The use of such soils is not possible unless reclamation measures are taken. The study of the work of drainage in different environmental conditions made it possible to conclude about the degree of its effect on soil fertility [1, 2]. In 80s years of the last century the transition to draining agricultural land by closed drainage began [3, 4]. But on heavy soils, closed drainage was sometimes ineffective in timely draining excess water. As a rule, this was due to the absence of hydraulic connection of arable horizon with a drainage pipe [5]. This problem was faced on the plain Huaibei in China. The use of a well filtering filling of the drainage trench led to an increase in the drainage flow by 1.9 times [6]. Studies of various constructions of subsoil drainage during the drainage of agricultural land in the floodplain of the Moldova River showed the advantage of the construction with the use of filtering drainage filling based on flax [7]. Studies to improve the drainage efficiency of poorly permeable soils in Belarus
allowed developing various filter column designs for the formation of a hydraulic connection between arable horizon and a drainage pipe \[8, 9, 10\]. That is why the problem of increasing the efficiency of drainage of agricultural land by closed drainage in environmental conditions of the Novgorod region remains still relevant.

### 2. Objects and methods of the research

The research objects are closed drainage systems having a hydraulic connection between arable horizon and a drainage pipe.

Experimental plots are situated in the Novgorod region on sod-podzolic loamy soil.

In the experiment the following kinds of design are used:
- standard drainage with filling the drainage trench with sand-gravel mixture (PGS) to arable horizon;
- two-tiered drainage.

The distance between the drains is 14 m, the depth is 1.1 m.

Designs of the two-tiered drainage systems provide for the upper tier of cavity-free drains with a depth of 0.5 m, and a distance of 6 m, located perpendicular to the lower tier.

The level of groundwater and soil moisture were identified by methods of Northern Research Institute of Hydraulic Engineering and Land Reclamation (Sev NIIGiM) \[11\].

### 3. Results and discussions

Studies of the efficiency of soil draining by closed drainage were carried out during 2017-2019.

Meteorological conditions for this period are presented in table 1.

| Year | Annual precipitation, mm | Average annual temperature, \(^{\circ}C\) | Amount of precipitation for the period from \(t>5^\circ C\) | Sum of temperatures over 5 degrees | Sum of precipitation for the period from \(t>10^\circ C\) | Sum of temperatures over 10 degrees | Hydrothermal Coefficient of Humidification (GTK) |
|------|--------------------------|-------------------------------|-------------------------|-------------------------------|------------------------|-------------------------------|----------------------------------|
| 2017 | 885                      | 5.7                           | 625                     | 2441                          | 481                    | 1782                          | 2.70                             |
| 2018 | 543                      | 6.1                           | 375                     | 2861                          | 274                    | 2501                          | 1.10                             |
| 2019 | 821                      | 6.8                           | 489                     | 2633                          | 392                    | 2231                          | 1.76                             |
| Norm | 550                      | 4.4                           | 385                     | 2311                          | 301                    | 2156                          | 1.40                             |

The experimental period is characterized by humidification conditions varying over years. In 2017 the annual precipitation sum exceeded the norm by 1.6 times, in 2019 – by 1.5 times, and only in 2018 it was within the normal range. The average annual temperature was the lowest for the research period in 2017, the highest - in 2019, but in all years it was higher than the average annual values. In 2018, the sum of active temperatures (above \(10^\circ C\)) exceeded the norm by \(345^\circ C\), and against the background of the lack of precipitation the year is characterized as a dry one.

In 2019, a large amount of precipitation, even against the background of high temperatures, caused excessive humidification during the growing season, and 2017 is characterized by Hydrothermal Coefficient (GTK) as abnormally humid (the amount of precipitation exceeded evaporation from the soil surface by 2.7 times).

The drainage system is designed to control soil moisture by the way of lowering the level of groundwater. Therefore, the level of groundwater is one of the important parameters of the efficiency of the reclamation system.
An analysis of the dynamics of groundwater in the experimental systems in wet years showed that in the year when there had been 1% of precipitation supply (2017), in the first half of the growing season, the groundwater had sunk to a greater depth in the two-tiered drainage systems which speaks of better discharge of groundwater compared to the collectors systems with sand-gravel mixture (PGS) (figure 1).

Figure 1. Levels of groundwater in the experimental systems.

In the third decade of July, after almost two norms of monthly precipitation had fallen, in the experimental systems groundwater began rising. Groundwater rose faster in the two-tiered drainage structure, which is related to more intensive removal of excess moisture from the arable horizon by the upper tier of drains.

In 2019 (5% of precipitation supply), during the entire growing season, the level of groundwater (UGV) in the two-tiered drainage systems was lower, though insignificantly, compared to the sand-gravel mixture (PGS) systems.

When analyzing the operation of drainage systems, it is more correctly to assess their efficiency by soil moisture regime.

Figure 2 shows graphs of moisture regime in the sand-gravel mixture (PGS) systems in soil layers: arable 0-30 cm, and root inhabited 0-60 cm.
Figure 2. Moisture reserves in the variant of sand-gravel mixture (PGS) dehumidifiers.
a) in an arable layer  
b) in a root inhibited layer.

Significant overmoistening of both an arable and a root layer was observed in dry 2018, in the first decade of May, after the double norm of precipitation had fallen in April. From the third decade of May, during the growing season, the lack of moisture was observed in soil, especially in June. In 2019, moisture was normal, for the exception of June, when drought was observed in the soil. In 2017, which was critical in terms of the amount of precipitation, the most overmoistening was observed in an arable layer, while in a root one it was optimal. This may indicate that these systems do not control enough effectively the removal of excess moisture from the arable horizon.

The two-tiered drainage systems provided a more favorable water-air regime in wet years. Overmoistening of the root inhibited layer was observed only in the first decade of May, 2018 (figure 3).
Figure 3. Moisture reserves in the option of two-tiered drainage systems.
a) in an arable layer
b) in a root layer.

The amplitude of moisture reserve fluctuations depends closely on the degree of a year humidification (table 2).

Table 2. Amplitude of fluctuations in moisture reserves, mm.

| Year | Sand-gravel mixture (PGS) backfill drainage | Two-tiered drainage |
|------|---------------------------------------------|---------------------|
|      | Layer, cm                                   |                     |
|      | 0-30 | 0-60 | 0-30 | 0-60 |
| 2017 | 40   | 50   | 35   | 60   |
| 2018 | 95   | 160  | 80   | 145  |
| 2019 | 50   | 70   | 30   | 70   |

Dependence of amplitude of fluctuations in moisture reserves on Hydrothermal Coefficient of

\[ A_w = -32,764\text{GTK} + 122.39 \quad (R^2 = 0.8086) \]

\[ A_w = -25,856\text{GTK} + 96.253 \quad (R^2 = 0.57) \]

\[ A_w = -50,242\text{GTK} + 184.78 \quad (R^2 = 0.7562) \]
Humidification (GTK) (determination coefficient)

With an increase of Hydrothermal Coefficient of Humidification (GTK) by one unit, the amplitude of fluctuations decreases in an arable layer by 29 mm, and in a root one – by 58 mm. The amplitude of fluctuations in moisture reserves also depends on the design of a collector. During the entire period of the investigations, in the arable layer this was greater in the sand-gravel mixture option (PGS), and in the root layer this depended on the level of humidification of the year.

4. Conclusion
In the experimental two-tiered drainage systems, in excess humid years groundwater did not rise into the arable layer throughout the growing season. After abundant precipitation, the formation of groundwater occurred faster in the two-tiered drainage systems.

The most favorable water-air regime with the different amount of precipitation, both in dry and abnormally wet years, was observed in the experimental two-tiered drainage systems with a smaller amplitude of fluctuations of moisture reserves in the arable soil layer.

So, the design of the collector based on two-tiered drainage provides higher drainage efficiency compared to the standard collector design.

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