Drainage reconstruction in the zone of excessive moisture during the cultivation of blueberries on poorly water-permeable clay soils

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Abstract. To ensure efficient agricultural production in the humid regions of Ukraine, drainage of wetlands is one of the first places. The area of drained lands is make up to 9.7% of the total arable lands in Ukraine. In 1990, 1,976.5 thousand hectares were used in active agricultural production, and the share of arable land on drained lands was 70.7%. Of the more than 1130 drainage systems with an area of more than 2.2 million hectares only 37% were built between 1980 and 1990, i.e. younger than 35 years. The remaining 63% of systems have been built and operated for more than 35 years. Since the 1990s, the construction of new and modernization of existing drainage systems in Ukraine has been almost non-existent. Maintenance of the systems was significantly reduced, which led to a significant deterioration in their technical condition, a change in the water regime of soils and the development of degradation processes. Traditionally, in Ukraine, a significant (1.4 million hectares) area is drained with ceramic drainage. We show the experience of reconstruction of the drainage system, which is located in the Pre-Carpathian Upland region of the Ukrainian Carpathians, the Middle Carpathian terrace plain, where a Drainage of Clay Pipes was built more than 35 years ago. The results of the analysis of the reasons of unsatisfactory drainage operation, identification of the most critical zones with the use of field research and earth remote sensing data are presented. To eliminate local wetlands, plastic drainage with a diameter of 50 mm is proposed. To increase the efficiency of its work on heavy clay soils with a filtration coefficient less than 0.01, the backfilling of the trench with local material – gravel with a fraction of 5...25 mm with geotextile protection. During the construction of the new drainage, ceramic drains of the previously constructed drainage were found. They were cleaned mechanically and connected through a filter backfill to the newly built drains.

1. Introduction
To ensure efficient agricultural production in the humid regions of Ukraine, the drainage of waterlogged lands occupies one of the first places. The area of drained land in Ukraine is 9.7% of the total area of arable land [1]. In 1990, 1,976.5 thousand hectares were used in active agricultural production, and the proportion of arable land on drained lands was 70.7%. Of the more than 1.13 thousand built drainage systems with an area of more than 2.2 million hectares, only 37% were built from 1980 to 1990, that is, today they are less than 35 years old. The remaining 63% of the systems have been built and have been in operation for over 35 years. Since the 1990s, the construction of new and modernization of existing drainage systems has not been carried out. Operational activities on already built systems have been significantly...
reduced, which led to a change in the water-physical properties of soils and the development of degradation processes. In Ukraine, a significant (1.4 million ha) area is drained by pottery drainage [2], [3].

The work aims to describe the reasons that led to the negative technical condition of drainage in the zone of excessive moisture in Ukraine and also describes a new approach to drainage renovation with limited funding on the example of reconstruction of drainage system the cultivation of blueberries on poorly water-permeable clay soils.

To achieve this aim, the following tasks were set:

- taking into account the agro-soil, topographic, hydrological and climatic features of the territory of the study area, determine the causes of local waterlogging, which lead to a decrease in the yield of blueberries;
- choose the most optimal way to localize the identified malfunctions of the existing drainage;
- describe the technology of renovation of the drainage system by the method of building a new drainage against the background of the maximum preservation of the efficiency of the existing drainage system.

2. Materials and methods

As is known, the main reasons for the unsatisfactory reclamation state of drained lands are the physical wear and tear of the elements of the drainage system (DS), violation of the rules for operating the system and the agricultural use of the drained lands themselves, the inconsistency of the applied design standards with modern requirements, miscalculations in surveys and calculations of the parameters of the drainage system, poor construction quality [4].

Therefore, for the successful use of the territories with built, but faulty drainage, it is necessary to carry out restoration work, which will ensure the optimal water regime of soils, and, accordingly, agricultural production at the required level. The issues of expediency of carrying out the reconstruction of drainage systems from an economic point of view are described in [5], and the use of systems with selective drainage in the reconstruction of drainage in the zone of Ukrainian Polissya is given in [6]. In addition to economic benefits, the reconstruction of drainage systems is often necessary to preserve the natural environment, in particular, from the negative factors of waterlogging in the drainage system itself and in the territories adjacent to it.

Therefore, the priority tasks of the Comprehensive Program for the Development of Land Reclamation and Improvement of the Ecological Condition of Irrigated and Drained Lands [7] are restoration of the functioning of reclamation systems that are in an unsatisfactory technical condition, but have not yet lost their potential, through the reconstruction and technical re-equipment of the on-farm system, which does not need significant capital investments [7]. The task was to ensure the sustainable functioning of the existing 3.15 million hectares of drainage systems, to reconstruct the drainage systems and improve the ecological condition of drained lands on an area of 46 thousand hectares, and from 2006-2010. another 134 thousand hectares (total 180 thousand hectares).

However, insufficient funding of both the program (out of the envisaged UAH 6.7 billion, actually UAH 5.1 billion, or 76.1%, was allocated from the state budget), and the entire structure of the State Water Agency led to the failure to fulfill the tasks set for the reconstruction of reclamation systems (figure 1) [8].

Fixed assets (minimum in 2006 - 76%, maximum in 2016 - 96%, and on average for 2015 ... 2021 - 93% of the funding of the State Water Agency included in the State Budget of Ukraine) are spent on the operation of national and inter-farm state drainage systems (figure 2). However, 36...45% of them are spent on wages, another 31...43% is spent on utilities and energy, and development costs are only 0.4...0.7% [9].
Figure 1. Funding for the operation of nationwide and inter-farm state drainage systems according to the State budget of Ukraine in hryvnias (UAH) and in terms of US dollars.

Figure 2. Structure of expenditures of the State budget of Ukraine in 2021 for the operation of the state water complex and water resources management.

Taking into account these amounts of funding, the possibility of reconstruction of the drainage systems is in rather small volumes than it have to be expected, further exploitation of the lands of a particular drainage system without its reconstruction will lead to significant material losses or endanger the population as flooding houses and structures, polluting drinking water, etc.

Consequently, the urgent need to carry out work to restore the functioning of the drainage on the one hand and the lack of funding on the other, encourages finding new approaches to drainage renovation, different from the option of building a new drainage network [10], [11]. In particular, it is proposed to carry out work on the partial reconstruction of areas whose damaged drainage, according to observations, leads to crop losses, and to leave the drainage that performs...
its functions.

3. Results and discussion

This paper shows an example of the reconstruction of the existing drainage from the newly built drip irrigation system with an area of 39.9 hectares for growing blueberries. The blueberry bushes are irrigated by a drip irrigation system built in 2019, and drained by a ceramic drains built over 35 years ago.

The object is located in the PreCarpathian elevated region of the Ukrainian Carpathians. The geomorphological region is the Middle Carpathian (Pridnestrovian) terraced plain. According to agro-soil zoning, it is an accumulative-denudation piedmont weakly dissected plain (N1 sQ) with sod-medium- and strongly podzolic surface-gleyed, mainly loamy, soils. In general, the Samborsko-Dolinsky region is transversely dissected, with sod-brown soils.

According to the hydrological zoning of Ukraine, the object of study is located within the Dniester-Prut region of high water content of the Ukrainian Carpathians. The Carpathian mountainous section of the Dniester River basin, where the drainage system under reconstruction is located, is mainly the upper right-bank part of the catchment area with a highly developed hydrographic network and is the main area for the formation of the Dniester River runoff. Here, from 800 to 1500 mm of precipitation falls annually, and the increased storm load on the northeastern slopes of the Carpathian Mountains causes excessive moisture in this zone and the occurrence of numerous flash floods, which is a characteristic feature of the Dniester regime as a whole. The average long-term values of the annual runoff module are the highest (4.70-5.33 l/s km2), and at the very source of the Dniester River this figure reaches 10.0 l/s km2. Therefore, about 26 off-farm drainage systems were built in the Dniester river basin until 1990, with a total area of 208329.0 ha. Among them are the largest: Vereshchitskaya, Tershakovskaya, Bolozovskaya, Tysmenitskaya, Shiretskaya, Dniester-Strvyazhskaya, Bystritskaya, Berezhnitskaya. Taking into account similar climatic, hydrological and soil conditions, the given experience of drainage reconstruction can be extended to a large area.

On (figure 3) shows the data for the reconstructed drainage area in terms of precipitation, as well as the maximum ($M_{s_{\text{max}}}$, $M_{r_{\text{max}}}$), average ($M_{s_{\text{a}}}$, $M_{r_{\text{a}}}$) and minimum ($M_{s_{\text{min}}}$, $M_{r_{\text{min}}}$) moisture values of the surface soil layer ($M_s$) and the root zone ($M_r$) for the period 2016 ... 2021. In particular, in 2020, the maximum amount of precipitation over the past 6 years was observed, which led to wetting and significant inhibition of plant development in a significant part of the system.

Also, in recent years, there has been a tendency for an increase in the frequency of cloudburst [12], [13], which significantly changes the conditions for the operation of drainage. In the study area, in particular in 2020, there were 15 cloudburst with an intensity of more than 20 mm/day, 8 with an intensity of more than 30 mm/day, and 2 with an intensity of more than 40 mm/day (figure 4, table 1). This uneven annual rainfall is another factor leading to an increase in the number and duration of waterlogged periods for plants.

Table 1. The amount of cloudburst on the drainage field, which is being reconstructed.

|                  | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|------------------|------|------|------|------|------|------|
| more than 20 mm  | 12   | 7    | 3    | 9    | 15   | 9    |
| more than 30 mm  | 4    | 4    | 1    | 4    | 8    | 3    |
| more than 40 mm  | 2    | 2    | 1    | 2    | 2    | 1    |
Figure 3. Data for the reconstructed site in terms of precipitation, as well as maximum ($M_s_{max}$, $M_r_{max}$), average ($M_s_{a}$, $M_r_{a}$) and minimum ($M_s_{min}$, $M_r_{min}$) moisture values of the surface soil layer ($M_s$) and root zone ($M_r$) for the period 2016 ... 2021.

To find out the reason why the drainage system built more than 35 years ago does not adequately drain excess groundwater over the entire area, which causes local waterlogging of crops, field and in-house studies were carried out in 2020-2021. The following causes of waterlogging have been found:

- the presence of a large number of closed depressions, in which melt water and storm water stagnate, which is due to the accepted agricultural technology for growing blueberries (figure 5) and the existing relief (figure 6);
- heavy mechanical composition of soils with a very low filtration coefficient (0.01 ... 0.005 m / day); – against the background of a generally high annual precipitation rate, there is a tendency for an increase in the maximum frequency and intensity of precipitation, which, against the background of a low infiltration capacity of soils, cause a high standing of the groundwater level;
- partial failure of the constructed drainage (as a result of natural processes of precipitation accumulation, soil shifts, destruction during the construction of trenches during the construction of pressure irrigation pipelines of the drip irrigation system and errors in the construction of drainage lines).

To find the actual location of the drains and compare them with archival design data, we abandoned traditional search methods (excavation and manual search) and terrestrial geophysical methods, including magnetic gradiometry and ground penetrating radar (GPR) [14], [15], [16], [17], due to inefficient GPR for providing detailed maps of subsurface drainage systems in large farm fields, significant labor losses and time [18], and when excavating – also due to the high probability of damaging the proper drainage.
Figure 4. Precipitation, air temperature, Soil moisture of the surface layer and in the root zone on the drainage field, which is being reconstructed.

Figure 5. Local depressions, in which stagnant water from melting snow and storm water.

Therefore, visible (VIS) satellite images of the site of different years were analyzed (figure 6). Multispectral (MS) and thermal infrared (TIR) images, as recommended when using of unmanned aerial vehicles (UAVs) in [18], [19], [20], were not used due to the low resolution of available satellite images. Sites of soil located directly above the drains, differ from more remote sites in terms of the conditions for plant growth, and primarily in terms of the amount of moisture
Figure 6. Detection of drains (Google Earth, date of shooting 07.20.2004, view from a height of 1 km, contrast adjustment +65%), (a) without, and (b) with drawn drains.

in the root layer [20]. Copies of archival schemes of subsurface drainage system installation were used to distinguish linear features representing drain lines from those representing farm field operations [18]. Figure 6 shows a fragment of an drained area in natural colors. Vegetation corresponds to rich green shades, a higher density of vegetation corresponds to brighter shades.

Figure 7. Using historical Google Earth images (shooting date 26/10/2006, view from a height of 1 km, contrast adjustment + 50%).

The obtained data on the placement of ceramic drainage were confirmed by visual inspection when the drainage collectors exit into open channels.

Satellite images also make it possible to identify problem areas in which drainage does not fulfill its functions or relief features create local zones of systematic waterlogging (figure 7). In such zones, the vegetation has an excellent color (figure 7), which is especially evident when using multispectral (MS) images. For example, in the image NDVI - Normalized Differential
Vegetation Index (B8A-B04) / (B8A + B04), (figure 8), zones in which NDVI-index is 0.35 are clearly visible, while zones with unoppressed vegetation have NDVI-index from 0.5 to 0.6.

Figure 8. NDVI image, date October 23, Sentinel-2 L2A, cloudiness 9%, angle 29°, 34 UGV.

After identifying the causes of waterlogging, the state and location of the existing pottery drainage, it was proposed to reconstruct the drainage network by installing additional drains in places of the greatest waterlogging (figure 9). To prevent the destruction of the existing pottery drainage, the depth of laying new polymer drains is taken at the level of the soil freezing depth (0.7 m) for the given area. This is on average 0.2 m higher than the existing pottery drains.

Drainage pipe PVC DN 50 (drainage) and DN 100 (collectors) was protected from silting by gravel filling, fractions 5...20 and 20...40 mm. The filter bed was placed in a “pocket” made of thermally bonded Typar SF 27 geotextile (figure 10, a), figure 11). The tube was laid on a layer of crushed stone, which was poured on top of the geotextile to increase water susceptibility. The geotextile was wrapped around the drainage filling (figure 11 a, pos. 3) at 0.2...0.3 m from the soil surface, and the trench was further covered with crushed stone (figure 11, a, pos. 1). This was done to protect the geotextile from being torn apart by agricultural implements during tillage.

When digging trenches, the existing pottery drainage was sometimes accidentally exposed. Then it was mechanically cleared to an accessible distance (figure 10, c), the destroyed tube was replaced with a perforated plastic one. To unload the part of the pottery drain located above, it was hydraulically connected to a new plastic drain through a filtering sanding (figure 11, b) and a pit filled with crushed stone (figure 11, b, pos. 9). The crushed stone in the pit was also protected from the ground by a layer of geotextile (figure 11, b, pos. 10).

4. Conclusions

In Ukraine, as in a number of other countries [5], [6], a significant number of drainage systems are operated, which, due to climate change, failure of individual drainage elements or a change in the purpose of the territory, do not fully provide drainage functions. With limited funding or in other cases, for example, if there is a desire to preserve perennial plantings, only part of
Figure 9. Layout of drains and collectors during the reconstruction of local areas.

Figure 10. Laying drainage: (a) - drainage sprinkling of crushed stone, protected by geotextiles; (b) - connection of drains to the collector through a coupling; (c) - randomly unearthed pottery drains.

The drainage system may be reconstructed. In this case, it is important to accurately map the existing drainage lines, find the places and causes of local waterlogging, and insert additional drainage with the possibility of intercepting the drainage flow from the existing one.

The method presented in the article for localizing disrepairs in existing drainage using new and archival satellite images can significantly reduce the complexity and duration of field studies to identify and mapping disrepairs of drainage. After accurately determining the location of existing drainage lines, the technology used to build shallow drainage on top of the existing one
allows you to maximize its performance and provide the necessary water regime for agricultural crops on poorly permeable soils.

This work is a continuation of the work [11], where theoretical and practical implementations are given introduces the application of a conformal mapping methodology for solving boundary value problems in order to calculate the filtration process in a horizontal drain, provided that the drains are installed at a different depth.

In the future, it is necessary to study in more detail the filtration process between drains intersecting at different depths and filter designs that will allow maximum unloading of the water flow from old drains to new ones, while protecting the latter from solid deposits entering them.

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