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У журналі відображено результати теоретичних та експериментальних досліджень із пріоритетних напрямів: агроресурси, водні ресурси, зрошення, осушення, гідрологія, екологія, гідротехніка, агроінженерія тощо. Журнал розрахований та буде корисним для науковців, фахівців водного та сільського господарства. Два видання журналу за рік публікують оригінальні наукові статті, а також огляди, пов'язані з профілем журналу.

Журнал включено до міжнародних та національних інформаційних та наукометричних баз, репозитаріїв і пошукових систем:

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Адреса редакції:
Інститут водних проблем і меліорації НААН
вул. Васильківська, 37, Київ, 03022
Тел. (044) 257-40-30, 067-791-67-11
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“LAND RECLAMATION AND WATER MANAGEMENT”

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FORMATION OF THE WATER REGIME OF THE SOIL ON DRAINED LANDS IN MODERN CLIMATE CONDITIONS

H.V. Voropai[1], Ph.D. in Technical Sciences, L.V. Kuzmych[2], Doctor of Engineering Sciences, N.B. Moleshcha[3], Ph.D. in Technical Sciences, O.I. Kharlamov[4], Ph.D. in Technical Sciences, I.V. Kotykovych[5], Ph.D. in Technical Sciences, O.A. Babitska[6], Ph.D. in Technical Sciences, M.G. Stetsiuk[7], M.D. Zosymchuk[8], Ph.D. in Agricultural Sciences.

[1] Institute of Water Problems and Land Reclamation of the NAAS, 03022, Kyiv, Ukraine;
https://orcid.org/0000-0002-5004-0727; e-mail: voropaig@ukr.net;
[2] Institute of Water Problems and Land Reclamation of the NAAS, 03022, Kyiv, Ukraine;
https://orcid.org/0000-0003-0727-0508; e-mail: kuzmychlyudmyla@gmail.com;
[3] Institute of Water Problems and Land Reclamation of the NAAS, 03022, Kyiv, Ukraine;
https://orcid.org/0000-0002-3207-2573; e-mail: sdp_2010@ukr.net;
[4] Institute of Water Problems and Land Reclamation of the NAAS, 03022, Kyiv, Ukraine;
https://orcid.org/0000-0002-9019-3445; e-mail: lharlam91l@gmail.com;
[5] Institute of Water Problems and Land Reclamation of the NAAS, 03022, Kyiv, Ukraine;
https://orcid.org/0000-0002-1492-3557; e-mail: ikotykovych@gmail.com;
[6] Institute of Water Problems and Land Reclamation of the NAAS, 03022, Kyiv, Ukraine;
https://orcid.org/0000-0002-9387-5943; e-mail: helena-babitska@ukr.net;
[7] Sarny Research Station of the IWPaLR of the NAAS, 34501, Sarny, Rivne region, Ukraine;
https://orcid.org/0000-0001-6773-2546; e-mail: nick.stetsiuk@gmail.com;
[8] Sarny Research Station of the IWPaLR of the NAAS, 34501, Sarny, Rivne region, Ukraine;
https://orcid.org/0000-0002-7162-8300; e-mail: zosimchykm@gmail.com

Abstract. *The results of analytical and field studies of the influence of modern climatic conditions on the formation of the soil water regime on drained lands are presented. It has been determined that an increase in air temperature and uneven distribution, changes in the nature, intensity, and structure of precipitation, and an increase in the number of cases of heavy rainfall, which are local during the warm period of the year, do not allow for the effective accumulation of moisture in the soil. The formation of new conditions for the cultivation of crops and changes in the directions of the use of drained lands requires expanding the functional tasks of drainage systems and improving the efficiency of water regulation on drained lands. Due to the discrepancy between the technological integrity embedded in the existing drainage systems at the stage of their design, the technical and technological capabilities of the systems, and the modern infrastructure of the users of drained lands, operational management of the technological processes of water regulation and maintenance of the optimal water regime of the soil is not ensured today.*

Studies at production sites on drainage systems typical for the drainage reclamation zone have established that carrying out a set of works to restore the channels of the open and collector-drainage network to design indicators, repairing and equipping hydraulic structures, the presence on the drainage systems of the possibility of water accumulation and the use of irrigation systems (drum-type sprinkler), made it possible to regulate the water regime of the soil and maintain humidity in the active soil layer within the limits close to optimal during the growing season. By regulating the groundwater level, the increase in the yield of crops was: spring wheat – by 19.8 %, oats – by 26.5 %, corn for grain – by 24.6 %, and soybeans – by 48.0 %. The cost of the increase in yield obtained by the water regime regulation during the study period averaged: spring wheat – 5.1 thousand UAH, oats – 4.8 thousand UAH, corn for grain – 12.9 thousand UAH, soybeans – 16.0 thousand UAH for 1 hectare. Information materials on the influence of modern climatic conditions on the formation of the soil water regime on reclaimed lands were obtained, which serve as the basis for the development of a methodology for substantiating the parameters for managing the soil water regime on reclaimed lands, taking into account the peculiarities of its formation under modern economic conditions and climate change.

Key words: *drainage system, drained lands, climate changes, soil water regime, water regulation*

Relevance of research. Globally, climate changes are manifested in different ways in the regions of the globe, and their impact on the state of the environment and socio-economic development of the regions is becoming more and more noticeable and is turning into one of the key problems. Climate change already today poses a potentially serious threat to the global economy and international security due to the increase in risks of various levels, which are associated with providing the population with food, drinking water and the stable existence of ecosystems [1–3].

First of all, climate change has a significant impact on agricultural production, one of the most climate-sensitive sectors of the economy. They lead to a lack of moisture supply, which is the main limiting factor in the sustainable functioning of agriculture [4–8]. The impact of weather conditions on yield is on average 52 % [9]. Therefore, in the context of climate change, modern agriculture needs to develop and implement measures to adapt to it [10].

Modern climate changes make adjustments to technological maps and the structure of crop rotations of agricultural enterprises in the drainage reclamation zone. At the same time, a number of economically attractive crops (corn, sunflower, soybeans, rapeseed, etc.) have taken leading positions in agricultural production, the cultivation of which is subject to the conditions of the agricultural market [11].

Considering that climate change impedes sustainable agricultural production, there is a need to use the potential of drainage systems, which is an untapped resource for increasing the efficiency of agricultural production through the introduction of modern technologies for growing economically attractive crops and obtaining stable yields [12]. At the same time, the formation of new conditions for growing crops and changing the directions of use of drained lands determines the need to expand the functional tasks of drainage systems and restore water regulation on drained lands.

Taking into account changes in natural moisture supply, an important limiting factor for the effective management of modern agricultural production is the reserves of moisture in the active layer of soil, the required amount of which is not provided during the growing season also on drained areas.

Analysis of the latest research and publications shows that climatic changes are manifested in an increase in air temperature, the average annual indicator of which in the period 1991–2020 compared to the period 1961–1990, in general, in Ukraine, increased by 1.2 °C. At the same time, in the zone of drainage reclamation, its increase is more significant: in the western regions – by 1.2–1.3 °C, in the northern and central regions – by 1.4–1.5 °C [3, 5, 13, 14].

In general, there is an increase in the duration of the warm period in Ukraine, which begins 15–20 days earlier in the spring and ends 1–6 days later in the autumn, while in Polissia and Forest Steppe zones, the duration of the warm period increased by an average of 4–10 days.

According to the estimates of world and domestic climatologists, there is a high probability of a further increase in air temperature in the future both on a global scale and in various natural and climatic regions of Ukraine [9, 10, 14–17].

Atmospheric precipitation is one of the main factors that determine the features of the regional climate. Their quantity and seasonal distribution are determining indicators of the formation of the territory’s wetting regime, which determine the hydrological regime, the nature of soil wetting and other characteristics of the ecological state and climatic resources. In contrast to the air temperature, the annual amount of atmospheric precipitation compared for the periods 1991–2020 and 1961–1990, both in Ukraine in general and in the drainage reclamation area, changed insignificantly (within 5–10 %). The general trend is the redistribution of their seasonal and monthly amount, which is manifested in a decrease in the amount of precipitation in winter and summer and an increase in spring and autumn. The decrease in the amount of precipitation during the growing season is most noticeable for the drainage reclamation zone in the Kyiv, Vinnytsia, Zhytomyr, and Chernihiv regions, whose territories already today correspond to the zone of insufficient hydration in terms of water availability. In the autumn period, especially in October, a significant (up to 20 %) increase in precipitation is noted [18, 19].

With an insignificant change in the amount of atmospheric precipitation in general for the territory of Ukraine, the nature and intensity of their precipitation has changed noticeably [20, 21]. Their structure has also changed, which with a significant increase in air temperature in the cold period is manifested in an increase in the frequency of rains and a decrease in snowfall and an increase in the number of cases of wet and sleet snow; in the warm period – in a decrease in the number of days with rains, an increase in the number of days with showers, and an increase in the duration of the rainless period [18].

The increase in the probability of excessive precipitation is noted in the reports of the

Intergovernmental Panel on Climate Change (IPCC). It is noted that against the background of moderate changes in the total amount of precipitation, their daily amount in many regions of the planet has significant positive trends [22].

In Ukraine, excessive precipitation in summer can have particularly dangerous consequences, including the formation of floods in any region of the country, especially in the west [23]. Therefore, their consideration is particularly relevant for the adaptation of the economy, especially the agricultural sector [24].

Literary sources indicate that at the beginning of the 21st century, both in Ukraine in general and in the area of drainage reclamations, there is a tendency to increase the number of heavy downpours (the amount of precipitation is 30 mm or more, falling in 1 hour or less). The largest number of heavy downpours in the period 1986–2015 occurred in the Ivano-Frankivsk and Transcarpathian regions, slightly less in the Kyiv, Cherkasy, Chernivtsi, and Lviv regions. In the period 2001–2010, the number of heavy downpours more than doubled from 1991–2000. In 2011–2015, the number of heavy downpour attacks in Kyiv and Chernihiv regions increased significantly [22, 25–27].

In the period 1991–2015, the largest number of rains in the area of drainage reclamations was observed in June and July. Heavy downpours with 30–40 mm of precipitation are frequent. It was established that there is a close relationship between the duration of rains and their average intensity. The highest average intensity values are observed during short-term rains. The longer the downpour, the lower its average intensity [28, 34].

Despite the wide range of possible future changes in the average amount of atmospheric precipitation, it is predicted that extreme precipitation in all seasons may become more intense, which will cause an increase in the number of high water days per year by 10–25 % and surface runoff and rain floods by the end of the century [29, 30].

An increase in air temperature and uneven distribution, change in the nature, intensity, structure of precipitation and an increase in the number of cases of heavy downpours, which are local in the warm period of the year, do not allow for effective accumulation of moisture in the soil. In general, the frequency of droughts in different soil-climatic zones of Ukraine has increased by 20–40 %, which prevents sustainable agricultural production also in the zone of sufficient atmospheric moisture, which covers Polissia and the northern territories of the Forest-Steppe.

Deterioration of the conditions of natural moisture supply in an increasingly large part of the territory of the zone of drainage reclamation, as well as the formation of conditions not only of overwetting of soils, but also of moisture deficit in them, especially in the second half of the growing season, increases the role of drainage systems in the sustainable management of agriculture on drained lands [31, 32].

As a result of climatic conditions, there was a change in the specialization of agricultural production, which changed the structure of cultivated areas. Traditional crops (rye, oats, corn for silage, flax, sugar beets, etc.) were replaced by economically attractive ones (corn, sunflower, soybeans, etc.), the cultivation of which is subject to the market conditions of agricultural goods. Since modern agricultural production is accompanied by non-observance of crop rotations and inadequate scientific justification of agrotechnical and hydromelioration measures, for the effective use of drained lands it is necessary not only to develop the structure of cultivated areas, but also water regulation technologies that take into account the specialization and needs of modern agricultural production [11, 31].

The latest studies and publications show that modern climate changes are one of the main factors that determine the conditions for the formation of the water regime of the soil on drained land, affect the water supply of reclaimed territories and the technical and technological features of the functioning of drainage systems, the water regulation capacity of which depends on the effectiveness of water regulation technologies soil regime [33–35].

The impact of climatic changes on the natural moisture supply of drained territories and the requirements of modern agricultural production to ensure water regulation on reclaimed land during the cultivation of economically attractive crops make it necessary to conduct research into the processes of forming the water regime of the soil under the conditions of the functioning of drainage systems, taking into account various regime-forming factors.

The aim of the research is to study the influence of modern climatic conditions on the formation of the soil water regime on drained areas.

Materials and methods of research. The basis of methodological approaches to conducting field research is the use of generally accepted methods for conducting meteorological observations (air temperature and precipitation), determining the groundwater level (GWL), soil moisture, biometric characteristics (the onset of the main phenological phases, yield) of crops during the growing season.

Measurements of groundwater levels in the field experiment were carried out using pentads. To determine soil moisture using the thermostat-weight method, ten-day sampling was carried out in the experimental plots along the depth of the root layer of the soil.

Sowing and caring for the studied crops were carried out following generally accepted technologies for their cultivation using mechanisms and tools directly in production conditions. Crop harvest recording was carried out using a continuous method throughout the entire recording area.

Research results and discussion. To study the processes of formation of the water regime of soils on reclaimed lands, experimental production sites were selected on drainage systems typical for the drainage reclamation zone (taking into account natural and climatic conditions and design and technological features) in the Rivne, Volyn and Sumy regions: reclamation systems of the Sarnenska Research Station (SRS) IWPaLR of NAAN and Agrarian Polygon LLC "ZAHIDAGROPROM" (Rivne region), drainage-irrigation system (DIS) "Romen" (SE DG "Nadyua" NAAN, Sumskyi region), drainage systems (DS) "Melnytska" and "Bobrovka" (Volyn region).

According to the research methodology, meteorological parameters were determined on the reclamation system of the SRS at the meteorological post of the station. It was established that in the growing season of 2022, 244.3 mm of precipitation fell, which is 155.7 mm less than the average long-term norm. Precipitations fell extremely unevenly, and more than 80 % of total amount were torrential rains (Fig. 1).

May was especially cold, with the average monthly temperature 1.4 °C lower than normal; during June, July and August – higher by 3.2, respectively; 1.2 and 2.6 °C, and in September – 2.8 °C lower than the long-term norm (Fig. 2).

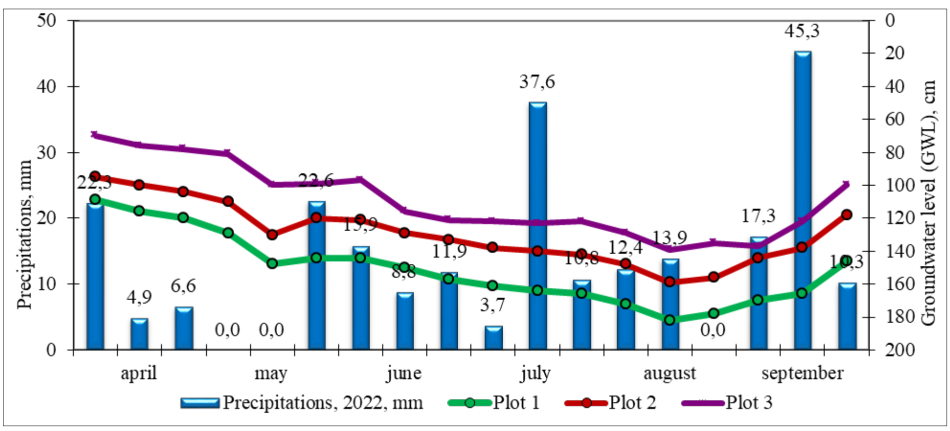

Fig. 1. Precipitation and dynamics of the groundwater level (GWL) in the 2022 growing season, reclamation system of the Sarnenska Research Station (SRS)

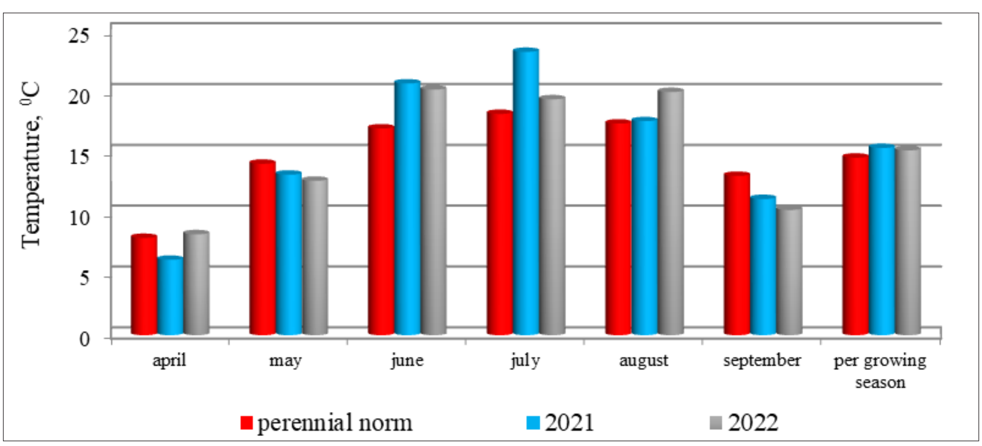

Fig. 2. Average monthly air temperature in the growing season of 2022, SRS reclamation system

The following promising crops were studied in the field experiment based on the basic cultivation technology on the background of 3 variants of GWL maintenance: spring wheat – Kitri variety, oats – Zubr variety, winter rape – Atlant variety, corn for grain – DK 315 hybrid, soybean – Astor. Regulation of the water regime of the soil in the experimental areas was carried out with the help of sluicing. During the growing season of 2022, observations of GLW were carried out at the experimental sites, the results of which are shown in Fig. 1.

It was established that in the conditions of 2022, high productivity indicators were obtained for all studied crops, and the potential of corn grain of the DK 315 hybrid of the Dekalb (USA) selection was 100 % realized. Depending on the GWL, the yield of spring wheat was 53.5–64.1; oats – 43.4–54.9; corn per grain – 147.1–183.3 and soybean – 28.1–41.1 t/ha (Table 1).

1. Crop productivity on the background of 3 options of GWL's maintaining on sod-podzolic light loamy soils

Crop	Variety/ hybrid	Yielb by the GWL options, c/ha		
		100–140	85–100	75–85
spring wheat	Kitri	53.5	58.9	64.1
oat	Zubr	43.4	49.1	54.9
corn	DK 315	147.1	173.9	183.3
soybean	Astor	28.1	36.3	41.1

Due to the regulation of GWL, the increase in yield for spring wheat was 19.8 %, oats – 26.5 %, corn for grain – 24.6 % and soybean – 48.0 %. Among the studied crops, soybean is the most sensitive to moisture supply.

The average cost of the increase in yield obtained by regulating the water regime was: spring wheat – 5.1 thousand UAH, oats – 4.8 thousand UAH, corn for grain – 12.9 thousand UAH, soybeans – 16.0 thousand UAH for 1 hectare.

Determination of meteorological parameters on the drainage systems "Maryanivka" and "Olshanka" was carried out at the meteorological station of the Agrarian Polygon of "ZAKHIDAGROPROM" LLC (Figs. 3, 4).

It was established that 445.3 mm of atmospheric precipitation fell in the 2022 growing season, which is close to the average long-term norm. June (90.4 mm), July (112.6 mm) and September (87.3 mm) were the wettest months. The warmest months were June and August – average monthly temperatures were 20.2 and 20.0 °C, respectively.

In production conditions, according to the basic technology of agricultural production, the research was carried out during the cultivation of the following crops: winter rye – KVS Eterno, winter rapeseed – KVS Alvaro, winter wheat – KVS Ronin, sunflower – Sumiko, corn for grain – LN30273.

In 2021, at the "Maryanivka" DS, a complex of works was carried out on the restoration of open channels and the collector and drainage network to the design parameters and the completion of hydrotechnical structures and restoration of their stability. At the same time, within the boundaries of the "Vilshanka" DS, irrigation was implemented on an area of 80 hectares. The system was used to accumulate additional volumes of water in the MK-1 channel (length 1000 m), which made it possible to provide irrigation during dry periods of growing crops using a drum-type sprinkler.

Therefore, the renewal of both systems made it possible to ensure the regulation of the water regime of the soil and maintain the moisture of the active layer of the soil during the cultivation of the studied crops within optimal

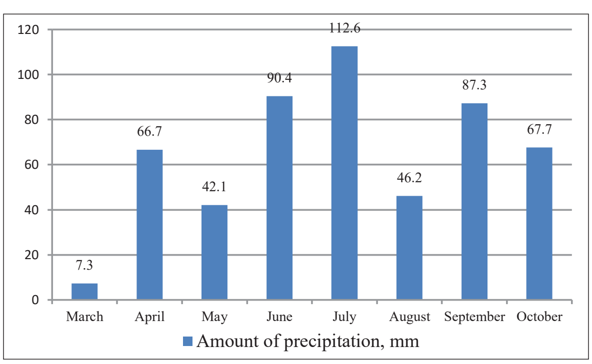

Fig. 3. Precipitation, growing season of 2022, DS "Maryanivka" and "Olshanka"

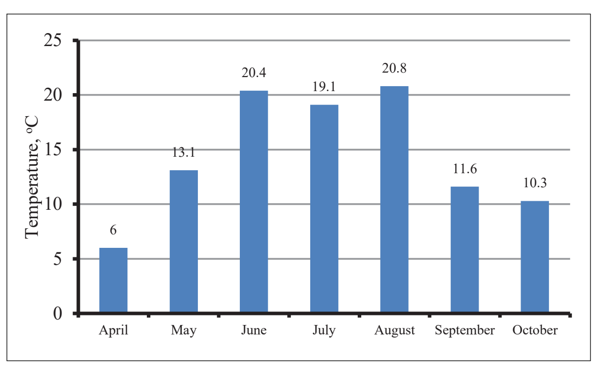

Fig. 4. Average monthly air temperature, growing season of 2022, DS "Maryanivka" and "Olshanka"

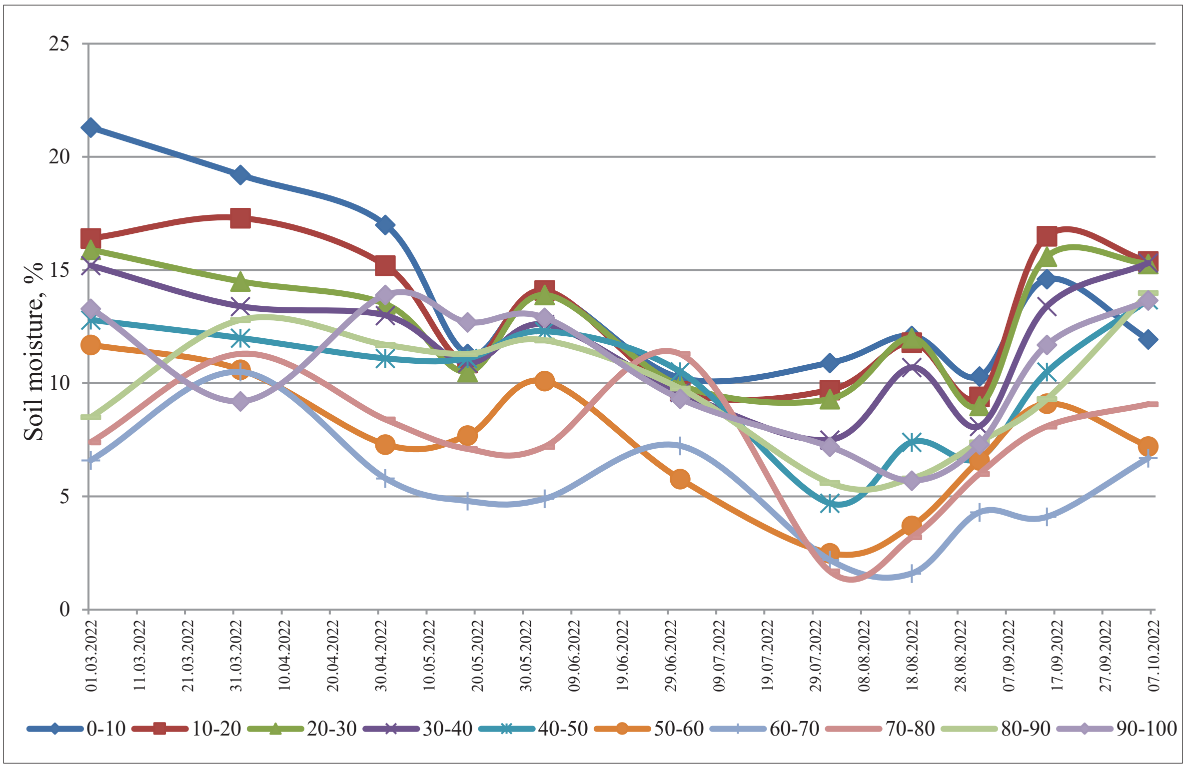

Fig. 5. Moisture's dynamics in the active soil layer, the growing season of 2022, DS "Maryanivka" and "Olshanka"

limits throughout the entire growing season. The dynamics of soil moisture in the aeration zone is presented in Fig. 5.

The yield characteristics of the studied crops were established (Table 2).

2. Yield of crops on the drained lands of the agrarian landfill of "ZAHID AGROPROM" LLC, Rivne region.

№	Crop	Area, ha	Yield, t/ha
1	winter rye	220.0	5.4
2	winter rape	210.0	2.8
3	winter wheat	154.0	6.2
4	sunflower	139.4	3.4
5	Corn for grain	420.0	9.2
Total		1143.4	

Indicators of meteorological factors (precipitation, air temperature) were determined on reclaimed lands of the "Romen" drainage and irrigation system (DIS) (Figs. 6, 7). It was established that in the growing season of 2022, the amount of precipitation was 493.6 mm, which is 171.6 mm more than the average long-term value. The average daily air temperature during the growing season was 1.7 °C less than the long-term value (14.5 °C) and only the average temperature for June was 0.8 °C higher.

Cultivated crops – plot No. 1: corn for grain mid-season hybrid DK315, FAO 310 (on an area of 1.5 hectares) and buckwheat of the Slobozhanka variety (on an area of 28 hectares); plot No. 2 – perennial grasses (on an area of 12 hectares); plot No. 3 – perennial grasses (on an area of 5.3 hectares).

Regulation of the soil water regime in the experimental plots was carried out using sluicing. If necessary, it is possible to supply water for humidification from existing water sources (storage tank, Karabutiv reservoir).

A study of the dynamics of GLW and moisture of the active soil layer during the growing season was conducted (Fig. 8, 9).

Under the conditions of the growing season of 2022 at experimental plot 1 (mineral soils), the actual GWL was on average within the following range: in May – 75–95 cm; June – 100–145 cm; July – 150–170 cm; August – 170–200 cm; September – 190–200 cm from the soil surface. Taking into account the fact that the GWL of the experimental plots at the end of the growing season were quite low from the surface, namely: in the spring period 0.6–1.2 m, during the summer 1.2–1.8 with a decrease until autumn within 2.0 m, the formation of soil moisture took place due to atmospheric precipitation.The GWL of plots 2 and 3 (peat soils) during the growi ng season

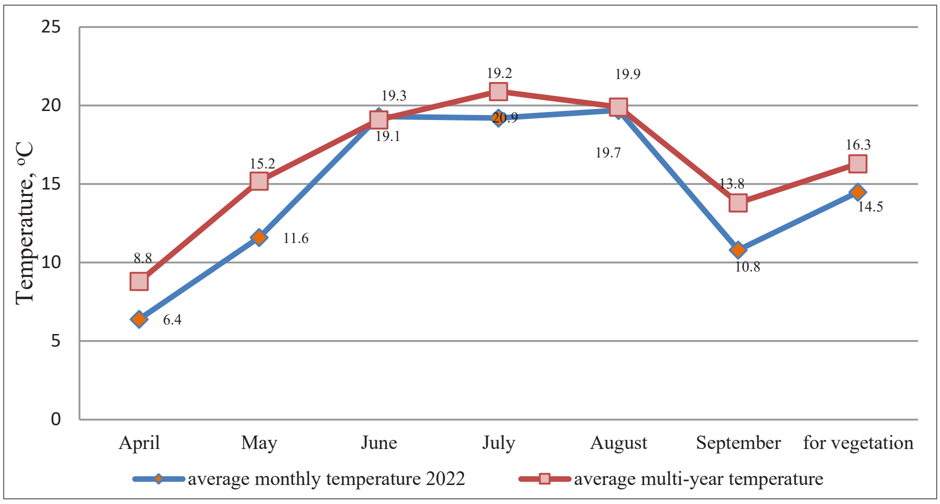

Fig. 6. Dynamics of average monthly air temperature during the growing season of 2022, DIS "Romen"

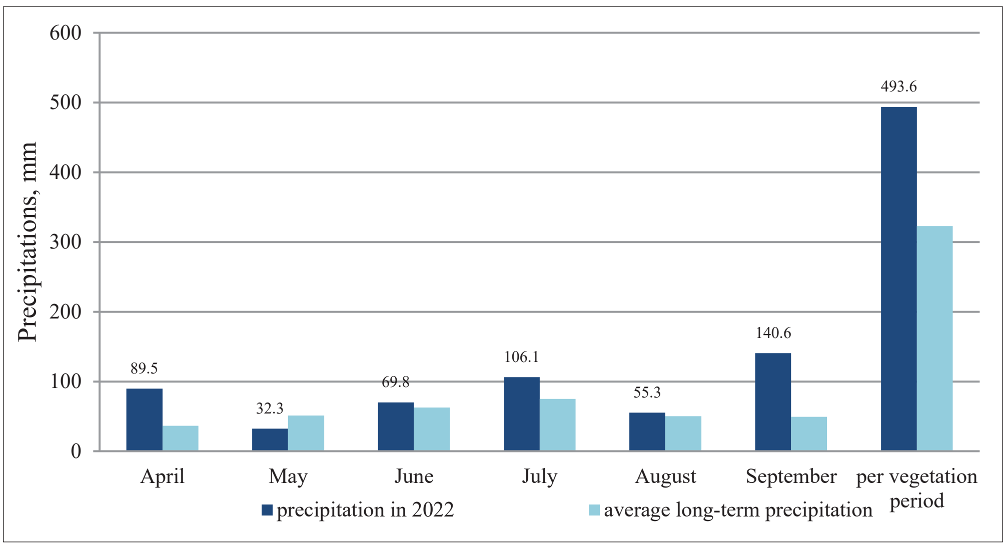

Fig. 7. Precipitations during the growing season of 2022, DIS "Romen"

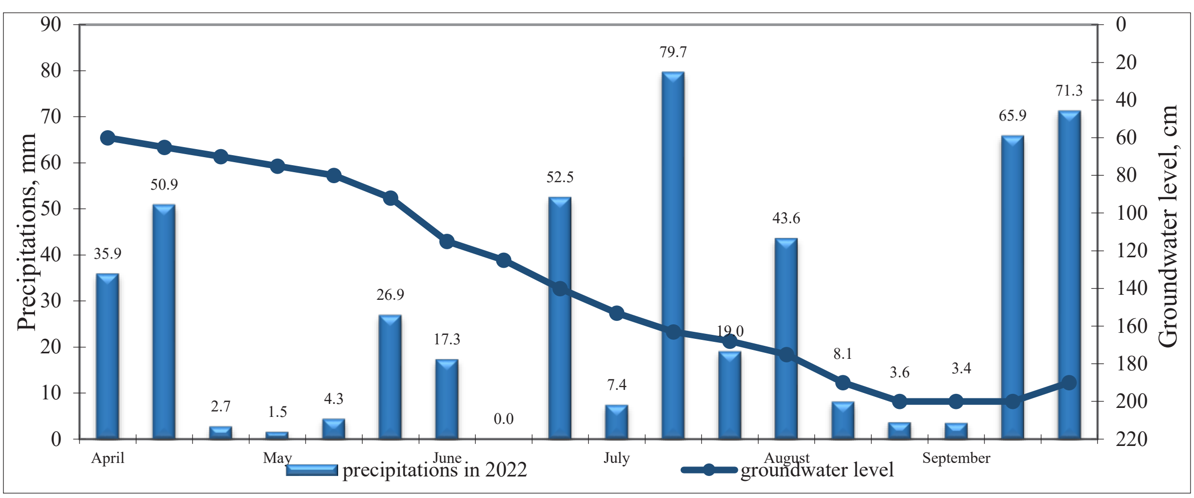

Fig. 8. Dynamics of GWL in the growing season of 2022, DIS "Romen"

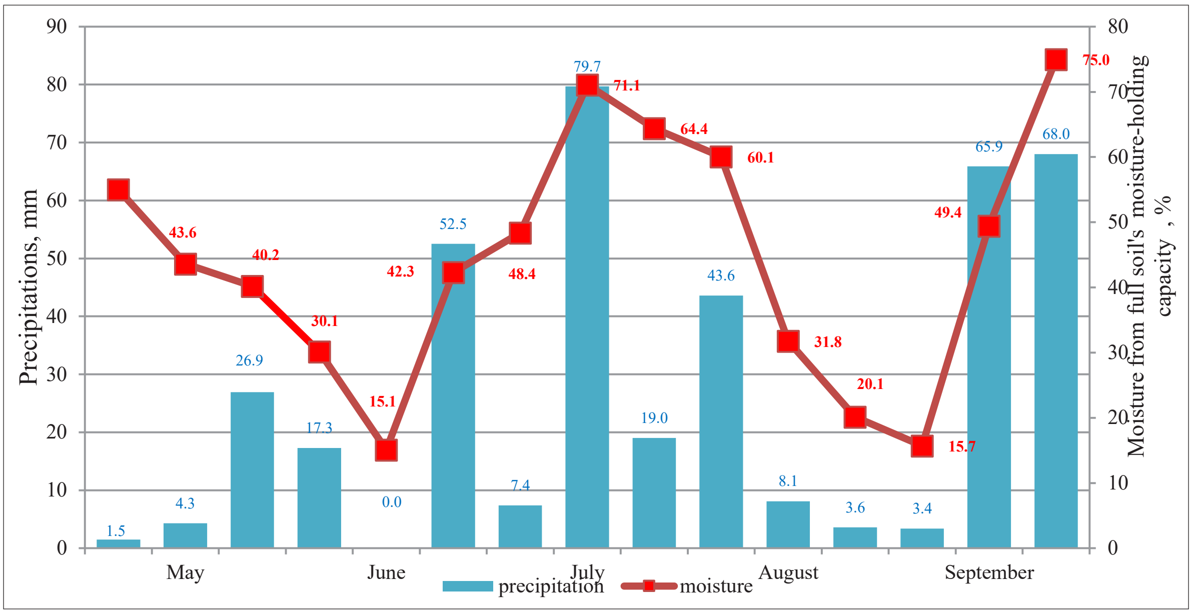

Fig. 9. Dynamics of moisture in the active soil layer (0–50 cm, peat soils) in the growing season of 2022, DIS "Romen"

was within the limits: in spring – 0–65 cm, in summer – 45–110 cm, in autumn – 50–115 cm from the soil surface.

The productivity of buckwheat and corn per grain was determined depending on the application of mineral fertilizers, respectively, at the rate of $N_{30}P_{30}K_{30}$ (for buckwheat) and $N_{60}P_{60}K_{60}$ (for corn per grain), which contributed to an increase in productivity by 26 and 38 %, respectively.

It was established that the yield of perennial grasses of 1 and 2 mowings, with different options for water regulation on peat soils, averaged 260 and 170 c/ha of green mass, respectively. High yields of perennial grasses of 1st and 2nd mowings were achieved in the area where water regulation is carried out through the use of steady drainage and moistening. The introduction of mineral fertilizers in all variants of the experiment helped to increase the yield of perennial grasses by 23 and 48 %, respectively.

Based on the results of research into the structural and technological parameters of the drainage systems (DS) "Melnytska" and "Bobrovka" (Kovelsky district, Volyn region), the need to restore the engineering infrastructure within the agricultural lands of the "Vasyuty" and "Bilynske" water treatment plant farms was established, and it was carried out clearing of drainage channels (up to design marks) and the mouths of drains and collectors from siltation, the operation of hydrotechnical structures has been restored (Fig. 10).

The dynamics of weather factors (Fig. 11), growth and biometric indicators of cultivated crops were observed at the experimental sites (Agricultural Limited Liability Company (ALLC) "Vasyuty" – sunflower and corn for grain; ALLC "Bilynske" – corn for grain and winter wheat),

Fig. 10. Technical condition of the MK-28 open channel and restoration of the mouth of the closed collector at DK-1 on the Melnytska DS

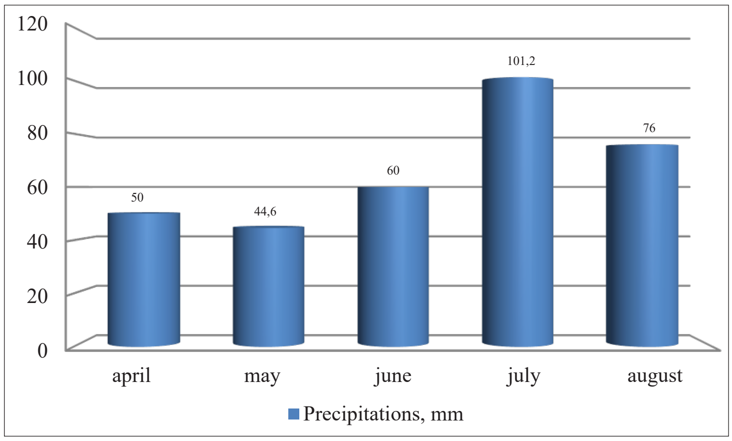

Fig. 11. Precipitations during the growing season of 2022, ALLC "Vasyuty"

Fig. 12. Dynamics of GWL in the growing season of 2022, ALLC "Vasyuty"

the water-physical properties of soils were determined, five observation wells were equipped to measure groundwater levels, and a study of the dynamics of RHV was conducted (Fig. 12).

On the reclaimed lands of ALLC "Vasyuty", according to the results of research (well No. 1, the cultivated crop is sunflower), the GWL in the period from the end of May to the middle of June was in the range of 0.28–1.1 m. Starting from the middle of June and until the beginning of August, the GWL gradually dropped to a mark of 2.3 m. Regulation of the water regime of the soil was not carried out. There was no water in the well since the beginning of August.

According to the results of research on the reclaimed lands of the ALLC "Vasyuty" (well 2, the cultivated crop is corn for grain), the GLW during the growing season was in the range of 0.5–1.4 m. From the end of July until the end of the growing season, growing corn for grain The GWL was at the marks 1.0 m lower than the soil surface.

On the reclaimed lands of the ALLC "Bilynske" (well 3, the cultivated crop is corn for grain), the GWL at the beginning of June was at the mark of 0.78 m. Subsequently, there was a gradual decrease in the GWL to 1.38 m (08/04/2022).

In the area where winter wheat was grown (well 4), by the beginning of June the GWL was at the level of 1.38 m, by the end of June (06/23/2022) the GWL reached the level of 1.77 m and subsequently there was no water in the well. Consequently, regulation of the soil water regime at the site was not carried out.

Conclusions. It has been determined that due to an increase in air temperature and uneven distribution, changes in the nature, intensity and structure of precipitation and an increase in the number of cases of heavy rainfall, which are local in the warm season, it is impossible to ensure effective accumulation of moisture in the soil. Due to the discrepancy between the technological integrity inherent in existing drainage systems at the stage of their design, the technical and technological capabilities of the systems and the modern infrastructure of users of drained land, today the operational management of technological processes of water regulation and maintaining the optimal water regime of the soil is not ensured.

Research at production sites of drainage systems typical for the drainage reclamation zone has established that carrying out a set of works to restore the channels of the open and collector-drainage network to design indicators, repairing and equipping hydraulic structures, the availability of drainage systems for accumulating additional water reserves for irrigation and the use of irrigation systems (drum-type sprinkler) made it possible to regulate the soil water regime and maintain humidity in the active soil layer within limits close to optimal during the growing season. It was determined that by regulating the groundwater level (GWL), the increase in crop yield was in the range of 20–48 %, and the cost of the increase in yield was 4.8–16.0 thousand UAH per 1 hectare.

Information materials were obtained on the influence of modern climatic conditions on the formation of the soil water regime on reclaimed lands, which will be the basis for the development of a methodology for substantiation of the parameters for managing the soil water regime on reclaimed lands, taking into account the peculiarities of its formation in modern economic conditions and climate change.

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ФОРМУВАННЯ ВОДНОГО РЕЖИМУ ҐРУНТУ НА ОСУШУВАНИХ ЗЕМЛЯХ У СУЧАСНИХ КЛІМАТИЧНИХ УМОВАХ

Г.В. Воропай[1], канд. техн. наук, Л.В. Кузьмич[2], докт. техн. наук, Н.Б. Молеща[3], канд. техн. наук, О.І. Харламов[4], канд. техн. наук, І.В. Котикович[5], канд. техн. наук, О.А. Бабіцька[6], канд. техн. наук, М.Г. Стецюк[7], М.Д. Зосимчук[8], канд. с.-г. наук

[1] Інститут водних проблем і меліорації НААН, 03022, м. Київ, Україна;
https://orcid.org/0000-0002-5004-0727; e-mail: voropaig@ukr.net;
[2] Інститут водних проблем і меліорації НААН, 03022, м. Київ, Україна;
https://orcid.org/0000-0003-0727-0508; e-mail: kuzmychlyudmyla@gmail.com;
[3] Інститут водних проблем і меліорації НААН, 03022, м. Київ, Україна;
https://orcid.org/0000-0002-3207-2573; e-mail: sdp_2010@ukr.net;
[4] Інститут водних проблем і меліорації НААН, 03022, м. Київ, Україна;
https://orcid.org/0000-0002-9019-3445; e-mail: lharlam91l@gmail.com;
[5] Інститут водних проблем і меліорації НААН, 03022, м. Київ, Україна;
https://orcid.org/0000-0002-1492-3557; e-mail: ikotykovych@gmail.com;
[6] Інститут водних проблем і меліорації НААН, 03022, м. Київ, Україна;
https://orcid.org/0000-0002-9387-5943; e-mail: helena-babitska@ukr.net;
[7] Сарненська дослідна станція ІВПіМ НААН, 34501, м. Сарни, Рівненська обл., Україна;
https://orcid.org/0000-0001-6773-2546; e-mail: nick.stetsiuk@gmail.com;
[8] Сарненська дослідна станція ІВПіМ НААН, 34501, м. Сарни, Рівненська обл., Україна;
https://orcid.org/0000-0002-7162-8300; e-mail: zosimchykm@gmail.com

Анотація. *Наведено результати аналітичних і натурних досліджень щодо впливу сучасних кліматичних умов на формування водного режиму ґрунту на осушуваних землях. Визначено, що підвищення температури повітря та нерівномірний розподіл, зміна характеру, інтенсивності, структури опадів і збільшення кількості випадків сильних злив, які мають локальний характер у теплий період року, не дозволяють забезпечити ефективне накопичення вологи в ґрунті. Формування нових умов вирощування сільськогосподарських культур і зміни напрямів використання осушуваних угідь вимагає розширення функціональних задач дренажних систем та підвищення ефективності водорегулювання на осушуваних землях. Через невідповідність між технологічною цілісністю, закладеною в існуючі дренажні системи на стадії їх проєктування, техніко-технологічними можливостями систем та сучасною інфраструктурою користувачів осушуваних земель, на сьогодні не забезпечується оперативне управління технологічними процесами водорегулювання та підтримання оптимального водного режиму ґрунту. Дослідженнями на виробничих ділянках на типових для зони осушувальних меліорацій дренажних системах встановлено, що проведення комплексу робіт із відновлення каналів відкритої та колекторно-дренажної мережі до проєктних показників, ремонт та укомплектування гідротехнічних споруд, наявність на дренажних системах можливостей акумулювання додаткових запасів води для проведення зволоження та застосування систем зрошення (дощувальної машини барабанного типу), дозволили забезпечити регулювання водного режиму ґрунту та підтримувати вологість в активному шарі ґрунту в межах, близьких до оптимальних, впродовж періоду вегетації. За рахунок регулювання рівня ґрунтових вод приріст урожайності вирощуваних культур становив: яра пшениця – на 19,8 %, овес – 26,5 %, кукурудза на зерно – 24,6 % та соя – 48,0 %. Вартість приросту урожаю, одержаного за рахунок регулювання водного режиму у досліджуваний період в середньому становила: яра пшениця – 5,1 тис. грн, овес – 4,8 тис. грн, кукурудза на зерно – 12,9 тис. грн, соя – 16,0 тис. грн на 1 га. Отримано інформаційні матеріали щодо впливу сучасних кліматичних умов на формування водного режиму ґрунту на меліорованих землях, які є основою для розроблення методології обґрунтування параметрів управління водним режимом ґрунту на меліорованих землях з урахуванням особливостей його формування в сучасних умовах господарювання та змін клімату.*

Ключові слова: *дренажна система, осушувані землі, зміни клімату, водний режим ґрунту, водорегулювання*

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TECHNICAL AND ECONOMIC ASPECTS OF THE IMPLEMENTATION OF WATER REMOVAL TARIFFS ON DRAINED LANDS OF UKRAINE

M.I. Romashchenko[1], Doctor of Technical Sciences, V.P. Panteleev[2], Doctor of Economic Sciences, R.V. Saidak[3], Ph.D. in Agricultural Sciences

[1] Kyiv Agrarian University of the National Academy of Agricultural Sciences of Ukraine, Kyiv, Ukraine; https://orcid.org/0000-0002-9997-1346; e-mail: mi.romashchenko@gmail.com;
[2] Kyiv Agrarian University of the National Academy of Agricultural Sciences of Ukraine, Kyiv, Ukraine; https://orcid.org/0000-0002-6979-8861; e-mail: bernstain@ukr.net;
[3] Institute of Water Problems and Land Reclamation of the National Academy of Agricultural Sciences of Ukraine, Kyiv, Ukraine; https://orcid.org/0000-0002-0213-0496; e-mail: saidak_r@ukr.net

Abstract. *The article highlights the main provisions of setting tariffs for water removal services for drainage. The application of tariffs is considered as an economic tool for increasing the efficiency of the use of drained lands when implementing the Strategy of Irrigation and Drainage in Ukraine [1]. An analysis of the provisions of the Law of Ukraine "On the Organization of Water Users and Stimulation of Hydrotechnical Land Reclamation"[2] regarding the provision of water users with water removal services for drainage by water user organizations and the payment of services by water users by the established water removal tariff was carried out. Emphasis is placed on the priority of the efforts in the field of hydraulic reclamation, namely proper operation and restoration of the country's drainage systems. The main point of the study is to realize the role of the status of water users who use water bodies to meet the needs of agriculture. According to the current legislation of Ukraine, the methodology of tariff formation should be based on a single basis – both for water supply and water removal.*

It is necessary to take into account the requirements of EU regulations regarding the consideration of the activities specifics in the field of water policy. Information on the development of water user organizations in Ukraine is provided and the operation costs of reclamation infrastructure facilities on the country's drainage systems are analyzed. The practice of foreign countries regarding the application of tariffs for water removal is given and the factors of the natural environment that were taken into account when selecting the option/options of water management in agriculture on drained lands of the country are outlined. The vision of researchers regarding the method of establishing and applying tariffs is given and a thorough assessment of the reasoning of scientists is provided. The areas for further research in the field of tariff formation for drainage are indicated. The base of tariff formation and methodical approaches to the formation of tariffs for water removal in the drainage area in Ukraine are proposed. The normative legal acts of Ukraine, the UN, EU bodies, the World Bank, data from scientific studies on tariff formation in agriculture on drained lands for 1991–2023, and administrative data were used as the main sources of information for the article.

Key words: *tariffs, water removal, tariff formation, reclamation infrastructure, drainage*

The relevance of the research. The responce to the challenges of the times is a sustainable course for the development and increase of the volume of agricultural production in Ukraine by ensuring the necessary water and air regime of the soil. Solving this task will require the application of economic mechanisms to increase the productivity of drained lands, in particular through the introduction of water removal tariffs for drainage, which is provided for in the Strategy of Irrigation and Drainage in Ukraine for the period until 2030 [1]. This economic instrument is considered as an important component of increasing the efficiency of drainage systems functioning in the Polissya area, along with their reconstruction and modernization into the combined irrigation systems and increasing the efficiency of drainage reclamation measures, growing new crops on the drained lands, which was previously impossible due to unfavorable natural conditions. Until now, tariffs for water removal in agriculture have not been applied in Ukraine.

The purpose of the study is to substantiate the main provisions of tariff formation for drainage by a unified approach to the formation of tariffs in Ukraine, based on the analysis of normative legal acts of Ukraine and a critical study of best practices in the application of tariffs for drainage needs.

Analysis of the latest research and publications. In literary sources, the issue of tariffs in irrigation is most often considered anong with drainage. Tariffs for water removal when draining land were not considered separately. The regulatory acts indicate the cost of services for irrigation of drained agricultural land, which is determined by water management organizations depending on the distance from a water distribution point [3]. The list of paid services includes: recommendations for improving the condition of water bodies and drained lands; services on water supply from reclamation systems and water sources for irrigation of drained lands and water regime regulation on combined irrigation systems [4]. The indicator "Area of drained land" provided by the recommendations on water resources statistics [5] is also used in Ukraine. In Ukraine, there are no publications regarding proposals for the introduction of water removal tariffs when draining.

Research methodology. Analysis of regulatory acts, learning the experience in providing paid services for the maintenance of reclamation systems of the drainage zone of Ukraine, critical study of best international practices in tariff formation for water removal services, logical and abstract methods (implementation of positive experience of using tariffs in drainage practice in Ukraine, attracting data from literary sources); analytical and synthetic methods (system analysis, generalization and synthesis of research results). The publication data were used to justify the mechanism of tariff formation for water removal services in Ukraine.

Research results and their discussion. By the statistical data as of January 1, 2021, that is, before the full-scale aggression of the Russian Federation, 5.48 million hectares of reclaimed land were accounted for in Ukraine, including 2.17 million hectares of irrigated and 3.3 million hectares of drained land with the appropriate reclamation infrastructure.

At the same time, the engineering infrastructure of the existing irrigation and drainage systems is out-of-date, practically physically worn out (more than 85 %) and needs reconstruction and modernization. The pumping and power equipment of reclamation systems is out-of-date and energy-consuming, its condition poses threats to ensuring water supply and removal during the irrigation season [6]. Given that a significant part of the infrastructure, especially the irrigation one, has been decommissioned due to damage, destruction or deprivation of water sources caused by the military actions of the Russian Federation, the need in necessary reconstruction measures in the post-war period is growing significantly. The progressive lack of natural water supply in the territory of Ukraine due to climate change even worsens the situation.

Therefore, in our opinion, a significant part of the drainage systems in the Polissia zone, which were less affected than the irrigation systems due to the Russian aggression, has to be reconstructed [1, 7, 22], without waiting for the end of the war.

In 2021, in Ukraine, bilateral water regulation was performed in the area of more than 300,000 hectares, which is less than 10 % of the available drainage areas. In addition, despite the important document adopted by the Cabinet of Ministers of Ukraine [1], the primary task of which is to restore drainage systems in the drainage area through their reconstruction and modernization and the Action Plan for its implementation [7], which defines the formation of a tariff system for drainage services, the process of increasing the areas of water regulation and introducing a tariff system for drainage has not started yet. The adoption in 2022 of the Law of Ukraine "On Water Users Associations and Stimulation of Hydrotechnical Reclamation" [2] did not activate this process, but its provisions enable to accelerate the development of the methodology for setting tariffs for water removal by drainage systems.

It is worth considering the status of the water user in water removal processes. According to the law, a water user is a private or legal person who uses water (water bodies) to meet the needs of the population, industry, agriculture, transport and other sectors of the economy, including the right to water withdrawal, discharge wastewater and other types of water use [8]. Water resources are qualified as partially non-renewable resources, i.e., they are those elements of the enterprise's property, the rate of recovery of which is lower than the level of economic consumption, therefore, at the enterprises effective measures should be taken to restore water resources, prevent or reduce water pollution, introduce the integrated water use, etc.

The above definition of water user by the legislation of Ukraine is closely related to the importance of water use [9], as a type of water services (any activity that has a significant impact on the status of water), namely the collection, accumulation, storage, treatment and distribution of surface or underground water; collection and treatment of wastewater, which is discharged then into surface water. All these are the functions of a water user. Dispite the fact that water removal/drainage of agricultural land differs significantly in terms of work technique from such a "canonical" and "stereotypical" land irrigation, is valued as an effective, necessary, technically justified type of water use, to which the principle provisions of irrigation tariffs can be applied to implement the water-regulating functions of drainage systems.

When applying economic levers (tools, water prices, tariffs, levies, taxes, subsidies, evaluation, financing and investment of some measures, etc.), the requirements of EU legal acts should be followed to take into account the specifics of activities in the field of water policy: implementation of the general program of measures for the effective use of water resources; following the rule of of water supply costs reimbursement, when the "polluter pays"; conducting an economic analysis of water supply services; collecting information and preparating relevant reports, etc. The member states of the European Union can thus take into account the social, environmental, and economic consequences of costs reimbursement, as well as the geographical and climatic conditions of the water supply of the regions. When implementing a sustainable water policy, the available scientific and technical data are taken into account, the potential benefit and cost of the measures or loss from not implementing water removal measures are estimated [10]. It is appropriate to note that the regulatory documents of Ukraine take into account the key requirement of the Directive – inter-basin and/or intra-basin redistribution of water resources [2].

The already mentioned Law [2] defines the legal status of water user associations (WUAs), the procedure for their establishing, operation and termination, etc. The law also regulates appropriate services for water users and the procedure of payment for them using the established water removal tariff. WUAs services include water removal from drained lands. WUAs serve the land plots of water users, from where water is removed for hydrotechnical amelioration needs. The water users' needs in engineering infrastructure of amelioration networks for water removal are determined. The regulations for water removal services provide for the existence of rules for the provision of water supply and removal services by the associations to water users and proposals from the water users regarding water removal, conclusion of a contract for services, and provide for payment by the water users for the services based on the water removal tariff.

The tariff includes the cost of services for water transportation and the cost of electricity necessary for water removal, as well as other costs, the size of which depends on the volume of removed water and the cost of maintaining the WUAs. The right of WUAs to stop providing services to the water users for water removal in case of delay in payment for WUAs services is also noted. It should be noted that the fact that the water user has paid for water removal/water regulation services is a requirement for state compensation for his losses.

In addition to the legally regulated works of the WUAs regarding water removal from the lands of water users, the researchers propose a wider range of relations between partners when removing water from drained lands. It is noted that tariffs for water removal should reflect the fact that drainage of one area may benefit not only farmers, but also other landowners elsewhere. Tariffs for drainage must ensure economic efficiency, financial sustainability and fiscal transparency, and also ensure equity, namely when rain on one land plot may cause a need for drainage on another, and consequently that drainage may benefit a third downstream area and such fair interactions usually involves the establishment of a single fee per hectare for the entire drainage area. Agricultural drainage can also help protect houses, roads and other infrastructure against flooding, so the funding system should ensure a fair balance between the various beneficiaries.

One special case is the combined irrigation systems found in the northwestern part of Ukraine, where open canals and closed drainage are used to lower the groundwater level in winter and early spring and to raise it in late spring and summer. Water used for irrigation often comes from an upstream drainage system, rather than from purpose-built irrigation canals, so its volumes cannot be measured. In most such cases, the most appropriate financing mechanism will be a single tariff per unit of both irrigation and drainage area during the year.

Upon acquisition of ownership rights to agricultural land plots, large farms may wish to build and operate their own pressure pumping stations and pipeline networks, so the WUAs should be ready to attract private investment to expand drainage area. At that the tariff system is expected to remain the same as it is for small farms that pump water directly from the canal to the irrigation system. However, the WUAs have to ensure that this approach will not lead to the situation when small landusers will not have an access to irrigation services and that private pumping stations will comply with the control system of water supply and distribution along the secondary canals.

First stage of the implementation of the Strategy includes: (a) reforming the system of water management and land reclamation by separating the functions between the State Water Agency and the newly formed business entity for managing the engineering infrastructure of irrigation and drainage systems (it has been implemented through the formation of the State Agency for Land Reclamation and Fisheries); (b) modernizing the system of monitoring and management of water resources in the State Water Agency and providing financing for the reconstruction of critical state water infrastructure within the State Fisheries Agency system; (c) developing the Law on the WUAs (the Law was adopted by the Verkhovna Rada of Ukraine in 2022) and starting establishing the WUAs (34 WUAs were established, in particular 4 in the drainage area: “Lesyni Dzherela” WUA on the Tesnivska system and “Tovscha” WUA on the Tnyanska system (Zhytomyr Region); “Sylna Voda” WUA on the Brovarka system (Kyiv Region) and “Subotiv” WUA on the Tyasmynska Drainage System (Cherkasy Region)) [13]; (d) forming financial mechanisms to support the investments of WUAs and farmers (the relevant procedure approved by the CM of Ukraine is applied); (e) establishing a regular structure and procedure for financing tariffs and subsidies [11].

The strategy stipulates finding a balance of the interests of the state, WUAs and water users and establishing the actual state of managing drainage facilities through inventory and timely implementation of measures for its improvement, improvement of operational practices and reasonable and effective spending of limited budgets. In some cases, it will be necessary to include in the tariffs the costs of improving water quality and the ecological condition of drained lands [12]. The application of tariffs for water removal will contribute to the efficient use of water resources and is considered as the provision of water services [9].

The formation of tariffs based on the cost of services for the transportation of water and electricity, necessary for water removal, increases the importance of the analysis of the actual costs of maintaining the infrastructure in the drainage area. It is necessary to compare the for operation costs for reclamation systems in Ukraine by the data of the State Water Agency of Ukraine for 2020. According to the data on the irrigation systems budget expenditures ranged from UAH 2.782/ha for the Black Sea and Lower Danube Basin Administration of Water Resources (BAWR) to UAH 3.481/ha for the Lower Dnipro BAWR and accounted for from 46 to 260 % of the total costs for their operation. The budget funding for the drainage systems of the Rivne region was much lower compared to the irrigation systems (139 UAH/ha), but its share in the total funding of the operating costs was significantly higher (more than 85 %) compared to irrigation systems.

This indicates that in the drainage area the state of the existing infrastructure of drainage systems is much worse compared to irrigation infrastructure, because the income from farms for the maintenance of drainage systems does not exceed 10 % of the budget funding. It is expected that introducing two-way regulation of the water regime with the help of more complex drainage and irrigation systems will provide farms with a guaranteed water regime for more efficient crop cultivation and will require greater participation of agricultural producers in financing the implementation of water regulation, which is possible only by increasing the tariffs for these services.

Practices of applying water removal tariffs in foreign countries. It is known from the history of irrigation of agricultural lands [14] that in the practice of draining lands, tariffs for water removal have been used for a long time. The table 1 provides the information about the practice of applying tariffs for water removal when draining land.

Legal relationships on water removal for drainage between free market agents, who benefit from the use of drained land, are formalized by the payment by water users of fixed and variable fees for services, area of drainage, use of water, etc.

The basis for the formation of tariffs in the drainage zone of Ukraine. On the basis of the current legislation of Ukraine, in particular the Law [2], the above analysis of the foreign practice in tariff formation, it is possible to propose the following provisions regarding the establishment of tariffs for water removal in the drainage area of Ukraine (Table 2). They should take into account the benefit as a result of reclamation systems operation, saving and rational use of water by farms, the category of land tenure, the implementation of high-quality climate-optimized water regulation technologies, the consequences of climate change, etc.

Increasing pressure on land and water use requires larger integrated drainage strategies, including the transfer of responsibility, decision-making and funding for irrigation and drainage systems from the public sector to water user associations.

1. Best practices in the application of tariffs for water removal in drainage services

Country, source	The practice of applying tariffs for water removal
The Netherlands [12]	Water boards/water administrations are responsible for land drainage and flood protection. Water board costs including the full cost of drainage are fully covered by water users.
Switzerland, Croatia [15]	It was established a fee for water removal in agriculture
Portugal, France [15]	It was established a fee for land drainage
Italy [15]	Consorzio di Bonifica e Irrigazione Company specialized in drainage and water supply uses 2 payment instruments: (i) tariffs and (ii) the self-service fee (both for abstraction of surface and groundwater). At the same time, the fee for water removal services is calculated in proportion to the benefit received (ranking plan) taking into account the served area. The organization splits the costs between drainage services and the supply of irrigation water to end users.
Serbia [16]	Based on the climatic conditions of the country, water excess causes higher economic costs than its deficit. Operation and maintenance costs have always been much higher for drainage than for irrigation, therefore, funds obtained as water removal fees must be earmarked funds used to maintain and improve the operation of publicly owned water bodies and systems used for drainage purposes.
Great Britain (England and Wales) [17]	It is considered that all land and property within the drainage district benefits from the drainage facilities and therefore the land owners are obliged to pay contributions to the operation and maintanence of the drainage facilities. Water removal and special fees have been established. The drainage fee includes a fee that combines a fixed right-of-delivery fee, based on the recovery of capital costs incurred in case of drainage works, and a variable fee per megaliter of distributed water. Both types of fee may differ depending on the category of land tenure, as it is specified in the List of Fees and Prices.
Australia [18]	Irrigation and drainage areas were transferred from state control to the private sector or under the control of water user cooperatives. There are capital and operating costs. The operation and maintenance costs for evaporation basins are covered by a tariff system based on a service fee, which includes a fee “per hectare” and “per megaliter”* when irrigating land. There is a service fee (annual cost for being connected to the system), an area fee (paid by all landowners in the area regardless of water use) and a water use fee, which is paid based on the total supply of water for irrigation.
*Megalitre ML = 1 000 cubic metres m^3 [5, p. 206]	
Georgia [19]	There are separate tariffs for irrigation and drainage services
India [20]	There is a fee for drainage maintenance. In the state of Tamil Nadu there is a fee for pumping and treatment of drainage water for agricultural needs.
Turkey [21]	Farmers, farmer cooperatives, or appropriate government agencies perform cost-effective cleaning and repair of subsurface drainage systems in case of clogged or visible damage to pipes or old sludge chambers.

Methodical approaches to the formation of water removal tariffs in the drainage area in Ukraine. The main goal of introducing tariffs on drainage systems of Ukraine should be reimbursement of costs, and the main measure of tariffs in drainage should be the fixed cost of services per hectare of area and the cost of removed water (in the areras where measuring devices are installed). On drainage systems, the basis of tariffs will be a fixed cost of services per hectare of drained land area, while on combined two-way drainage systems it is reasonable to apply a two-rate tariff, which includes a fixed rate per a unit of drainage area and a variable rate per a unit volume of water supplied to the plot or removed from the plot. In some cases, it may vary depending on crop type, and the more moisture-loving crop, the higher is the water fee. It is necessary to adapt the legislation in terms of introducing water removal and supply tariffs in accordance with the established rules, to enlarge public participation in water management, participation of water users in the development of the fariff system for water removal, as well as of the adaptation systems to climatic conditions. State support for maintanence, reconstruction

2. The general technical and economic basis for setting tariffs for water removal on reclamation systems in Ukraine

Elements of the tariff formation mechanism	On drainage systems	On combined two-way drainage systems
Land plots of the water users that require water removal (bilateral regulation), total area	area of the system, type of drainage	area of the system, type of drainage, availability of two-way water regulation
Reclamation facilities (reservoirs, canals, drains, pumping stations, roads, protective dams, observation network and other hydrotechnical structures and objects)	reclamation facilities provide water removal	reclamation facilities provide two-way water regulation
Rules for the provision of water supply and water removal services, developed by the WUAs, conditions of service provision, water user applications for the provision of water removal/water regulation services, contracts with the WUAs for water removal/water regulation services, compliance with the rules for the provision of the WUAs services to the water users, timely payment for services	existence of rules, contracts for water removal	existence of rules, contracts for water removal/water regulation
Schemes of engineering infrastructure facilities of reclamation networks, which ensure water delivery and removal for the needs of water users.	existence of schemes	existence of schemes
Developed tariffs for water removal /water regulation services; established fee for the WUAs services for water removal/water regulation; formation of the Budget Plan for maintenance of the systems, payment for electricity/fuel for the operation of pumping stations; income and expenses; schedule of services payment by water users by the tariffs	the cost of water and electricity transportation services necessary for water removal, as well as other costs, the amount of which depends on the volume of removed water, the costs for operation of the WUAs	the cost of water and electricity transportation services necessary for water removal, as well as other costs, the amount of which depends on the volume of removed water, the costs for operation of the WUAs
taking into account the changes in natural and climatic conditions, actual capability of water-regulating function of reclamation systems	water removal from the area	water removal and water supply to the area
*the possibility of introducing differentiated tariffs for services on drainage systems with pottery/plastic drainage and under different crops		
protection of the objects of state and communal property against flooding, damage, etc.	protection of the objects on the system	protection of the objects on the system
establishing the mechanisms to support the investments of the WUAs and farmers in improving the reclamation infrastructure	applying on the system	applying on the system
capability of transferring removed or supplied water from one area to another one	water removal from the area	water removal from the area and water supply to the area

and modernization of reclamation infrastructure should be maintained. The introduction of tariffs will require a higher level of qualification of workers in the field of drainage and agricultural use of reclaimed land, and personnel of the reclamation infrastructure management services. The level of self-organization of water users will be important.

Tariff formation should display the reclamation infrastructure management schemes, local and regional water removal/supply characteristics, water availability, structure and number of cultivated crops, use of alternative water-saving technologies, drainage/irrigation methods, and existing subsidy systems. Different regions and drainage facilities in Ukraine require different approaches to setting tariffs. The cost of services paid by water users will depend on the water intake facilities and the state water removal systems. A detailed economic analysis with different pricing scenarios for both drainage and irrigation tariffs will help to choose more efficient alternatives to the tariff system. At that, it is also necessary to take into account the need to develop effective mechanisms for controlling and accounting for the use of water resources, as well as the mechanisms of preventing the cases of unauthorized water withdrawal from natural water bodies.

The law [2] establishes the principles of tariff formation for water removal and the tariff components, specifies the activity of the WUAs on water removal and its cost, as well as the rules of providing services. The conditions for the performance of contracts for the provision of services are recognized as relevant for the parties. Based on the existing tariff formation mechanism, investments will be attracted in the modernization and restoration of the network of drainage systems, pumping stations, reduction of energy consumption and non-productive water losses.

The water-user as a business entity and a beneficiary, receives economic benefits from maintanence of optimal water and air regimes, which are formed as a result of proper functioning of drainage systems and water removal from them. Tariffs for water removal services for drainage, paid by the water user, connect the interests of the beneficiary, water removal service, territorial communities, the state, regional and national economy.

Conclusions. Applying tariffs in water removal is considered as an innovative area in the relations of water users and the state through the interaction of the WUAs. They must take into account the availability of engineering infrastructure facilities of reclamation networks, features and specifics of the reclamation complex, control the compliance with the requirements for ensuring hydraulic connectivity and technological integrity of reclamation systems. When transferring from the payment procedure for water removal services to the introduction of tariffs, it is advisable to use the successful experience of developed countries in terms of agriculture. The imperative of the state's interests under market conditions in developing drainage in the agricultural sector is manifested in the monitoring of the proper use of reclaimed land and control of the responsibility of landowners and the WUAs through services payment by tariffs. The aim of introducing paid water use based on drainage tariffs in Ukraine is a cost reimbursement. The fixed service cost per hectare of reclaimed land should be a main measure of tariffs in drainage.

The areas of further research should be the following: development of legislation in the area of introducing water removal tariffs, learning the current state of reforms in the introduction of tariffs, generalization of the best practices of managing reclamation infrastructure based on tariff application both in Ukraine and in the world, development of the method of applying tariffs for drainage systems, conducting a survey/study of the practices of tariff formation, development of adequate water drainage infrastructure management schemes and providing water services taking into account ecological and economic justifications.

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ТЕХНІКО-ЕКОНОМІЧНІ АСПЕКТИ ЗАПРОВАДЖЕННЯ ТАРИФІВ ІЗ ВОДОВІДВЕДЕННЯ НА ОСУШУВАНИХ ЗЕМЛЯХ УКРАЇНИ

М.І. Ромащенко [1], докт. техн. наук, В.П. Пантелеєв [2], докт. екон. наук, Р.В. Сайдак [3], канд. с.-г. наук,

[1] Київський аграрний університет НААН України, м. Київ, Україна;
https://orcid.org/0000-0002-9997-1346; e-mail: mi.romashchenko@gmail.com;
[2] Київський аграрний університет НААН України, м. Київ, Україна;
https://orcid.org/0000-0002-6979-8861; e-mail: bernstain@ukr.net;
[3] Інститут водних проблем і меліорації НААН України, м. Київ, Україна;
https://orcid.org/0000-0002-0213-0496; e-mail: saidak_r@ukr.net

Анотація. *У статті висвітлено основні положення встановлення тарифів на послуги з водовідведення для дренажу. Застосування тарифів розглядається як економічний інструмент підвищення ефективності використання осушуваних земель при реалізації Стратегії зрошення та дренажу в Україні [1]. Був проведений аналіз положень Закону України «Про організацію водокористувачів та стимулювання гідротехнічної меліорації земель»[2] щодо надання організаціями водокористувачів послуг із водовідведення для дренажу користувачам та сплаті водокористувачем послуг за встановленим тарифом на водовідведення. Наголошено на пріоритеті зусиль у сфері гідротехнічних меліорацій на експлуатації та відновленні осушувальних систем країни. Вихідним моментом дослідження є розуміння ролі статусу водокористувача, який використовує водні об'єкти для задоволення потреб сільського господарства. За чинним законодавством України, методологія тарифоутворення повинна ґрунтуватися на єдиній основі – як при подачі води, так й і її відведенні. Слід брати до уваги вимоги нормативних актів ЄС щодо врахування специфіки діяльності у галузі водної політики. Надано інформацію щодо розвитку організацій водокористувачів в Україні та проаналізовано витрати на експлуатацію об'єктів меліоративної інфраструктури на осушувальних системах країни. Викладено практику зарубіжних країн щодо застосування тарифів при відведенні води та зазначено чинники природного середовища, які враховувалися при відборі варіанту/варіантів управління гідросферою у землеробстві на осушених землях країни. Наведено бачення дослідників щодо методики встановлення та застосування тарифів та надана ґрунтовна оцінка міркуванням науковців; зазначено напрями подальших досліджень у сфері тарифоутворення для дренажу. Запропоновано базу формування тарифів та методичні підходи до формування тарифів на водовідведення у зоні осушення в Україні. Головними джерелами інформації статті стали нормативно-правові акти України, ООН, органів ЄС та World Bank, дані наукових досліджень із тарифоутворення у землеробстві на осушуваних землях за 1991–2023 рр., адміністративні дані.*

Ключові слова: *тарифи, водовідведення, тарифоутворення, меліоративна інфраструктура, дренаж*

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IDENTIFICATION OF DESTRUCTION AREAS OF RECLAMATION SYSTEMS AND EVALUATION OF IRRIGATED AGRICULTURE BY THE REMOTE SENSING DATA

T.V. Matiash[1], Ph.D. in Technical Sciences, Ya.O. Butenko[2], Ph.D. in Agricultural Sciences, A.V. Krucheniuk[3], A.F. Saliuk[4], N.V. Soroka[5], E.I. Matiash[6]

[1] Institute of Water Problems and Land Reclamation of the National Academy of Agricultural Sciences, Kyiv, Ukraine; https://orcid.org/0000-0003-1225-086X; e-mail: t.v.matiash@gmail.com;
[2] Institute of Water Problems and Land Reclamation of the National Academy of Agricultural Sciences, Kyiv, Ukraine; https://orcid.org/0000-0002-1743-7175; e-mail: iarynabulba@gmail.com;
[3] Institute of Water Problems and Land Reclamation of the National Academy of Agricultural Sciences, Kyiv, Ukraine; https://orcid.org/0000-0002-5850-2404; e-mail: anatolkru@gmail.com;
[4] Institute of Water Problems and Land Reclamation of the National Academy of Agricultural Sciences, Kyiv, Ukraine; https://orcid.org/0000-0003-3968-1125; e-mail: allasaluk@ukr.net;
[5] Institute of Water Problems and Land Reclamation of the National Academy of Agricultural Sciences, Kyiv, Ukraine; https://orcid.org/0000-0003-2868-1832; e-mail: natasha.voda.75@gmail.com;
[6] National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine; https://orcid.org/0009-0007-7079-3017; e-mail: liza.mymailbox@gmail.com

Abstract. *The article analyzes the results of using the decision-making support system to identify the destruction areas of reclamation systems and evaluates the state of irrigated agriculture by the remote sensing, as well as proves its ability to form and provide the user with preliminary information about the state of reclamation infrastructure. Most of the relatively new and functioning irrigation systems are currently out of the control of the Government of Ukraine due to the occupation of the Kherson and Zaporizhzhia regions by the Russians. Irrigation and drainage systems, over which control was restored and which were in the zone of direct hostilities, were in a destroyed state, and the undermining of the Kakhovska HPP by the occupiers makes it impossible to further use the irrigation systems of both the occupied and unoccupied parts of Ukraine, which were provided with water directly from the Kakhovska reservoir. To provide a rapid visual identification of destruction areas of reclamation systems for evaluating damage to irrigation and drainage infrastructure in 2023, the capabilities of the information system developed at the Institute of Water Problems and Land Reclamation of the National Academy of Agricultural Sciences of Ukraine have been expanded. On the example of the Odesa region, based on basic information about pumping stations of reclamation systems and available information using ACLED technology about hostilities, explosions, artillery attacks, etc., as a result of Russian aggression, a synthesized image was formed, which can be used for visual evaluation of the impact of hostilities on reclamation systems in both individual areas and the whole country. The information system was used for zoning regions by the intensity of military impacts and expected damage to the infrastructure of irrigation and drainage systems. The evaluation of indirect damage zones was carried out using remote sensing data by the NDVI index, which indicates a decrease in the accumulation of biomass in the areas of irrigation systems. The forecast for the further use of irrigated land is based on a statistical analysis of the data on the conclusion of contracts for special water use, which proved a four-fold decrease in water demand, planned for 2022.*

The study results can be used to evaluate the damage caused to Ukraine as a result of the war and confirm the devastating impact of the war on the irrigation and drainage sectors.

Key words: *remote sensing of the Earth, irrigation, information system, damage, irrigation management, special water use, irrigation*

The relevance of the research. Since 2022, because of the full-scale armed aggression of the Russian Federation in the territory of Ukraine, the agricultural sector of our country has been suffering from a significant negative impact of war. According to the FAO report [1], agriculture is of crucial importance for the economy of Ukraine. Before the war, it produced about 20 percent of the country’s GDP and more than 40 percent of the total revenue from exports, and its decline in the first year of the war amounted to more than 30 % [2]. The war is expected to continue to have far-reaching consequences for Ukraine's economic growth and affect global food security.

The war damaged agriculture and its infrastructure across the country, affecting irrigation, crop storage and processing facilities, machinery and equipment, port storage and transport infrastructure, greenhouses, livestock, etc. The carried out analysis indicates that as of July 2022, preliminary losses to the agricultural sector amount to 4.3–6.4 billion US dollars [3], that is 15–22 percent of the total value of the country's agriculture before the war, estimated at 29 billion US dollars. The actual figures are likely to be much higher, as the above estimates do not include the potential damage to the agricultural capital of smallholders located in war-affected areas, who on average produce about 40 percent of Ukraine's total agricultural production, which inevitably indicates a much greater losses in the sector.

Unfortunately, it is currently impossible to identify the real areas of damage caused by military actions and to calculate the actual damage on reclaimed systems due to a number of restrictions, in particular, due to active hostilities and the occupation of part of the territory. In this case, a remote sensing approach is the only possible way to estimate damage, especially on a larger scale – from point, regional to national scales. This approach is considered cost-effective and time-efficient, as a single image can be used to estimate damage over a large area [4].

This work is part of research conducted by the Institute of Water Problems and Land Reclamation of the National Academy of Agricultural Sciences of Ukraine to evaluate the damage and local needs experienced by reclamation systems and producers on these lands. For this purpose, territories that were unoccupied, de-occupied, and free of active hostilities as of January 31, 2023 were specifically studied. A general methodology, which included four key components: (1) surveys at the state and local levels of owners and producers on reclamation systems, (2) interviewing of territorial communities, (3) mapping and analysis of remote sensing data, (4) working with databases on armed conflicts and statistics published in the ACLED database for the period 24.02.2022–31.01.2023.

The result of processing a large amount of information was an economic evaluation of the losses suffered by reclamation systems and the producers working on reclaimed lands since the beginning of full-scale aggression. In this article, the authors present a part of the materials and methodology that were used to identify the areas of destruction of reclamation systems and evaluate the state of irrigated agriculture by the remote sensing data.

Analysis of recent research and publications. For the rebuilding of Ukraine, the "Plan for the post-war reconstruction of Ukraine" was developed, and the UNITED24 fundraising platform was established for cooperation with charitable foundations, partners, donors and public figures around the world. The World Bank (WB) together with the government of Ukraine, based on a joint evaluation of the ministries using the RDNA (Rapid Damage Need Assessment) method, evaluated the damage caused to Ukraine as a result of military operations. The results of this evaluation were approved by the Government of Ukraine [5].

In the first report made by the World Bank, the Government of Ukraine and the European Commission [5] on the evaluation of damage and recovery needs for Ukraine, the total amount of damage and recovery needs of the irrigation and water sector was estimated as $8 billion as of June 1, 2022. This amount partially includes the damages caused to water management infrastructure in the amount of $0.2 billion, and provides for the reconstruction of the irrigation and drainage sector by the principle of reconstruction at a qualitatively new level "We will rebuild better [than it was]", "Build Back Better", which is valued at $7.5 billion.

Based on the data of the Ministry of Agrarian Policy and Food, the Ministry of Environmental Protection and Natural Resources and the State Water Agency, as the balance keeper, a rapid damage, loss and needs assessment (RDNA) was conducted in the irrigation and drainage sector.

The Ministry of Agrarian Policy and Food deals with recording losses in the irrigation and drainage sector at the local level. In view of recording the effects of the war, this ministry is responsible for recording losses in the sectors of agriculture, land reclamation, and fisheries. The Ministry of Environmental Protection and Natural Resources of Ukraine and the State Water Agency record the damages to the surrounding natural environment, water resources, including damages to water management infrastructure. The State Environmental Inspection deals with the formation of a list of all breaches in the field of environmental protection (including water resources) during the war.

The ministries have developed and approved at the legislative level the methods of damage evaluation along with relevant cases [6]. These methods assume that the damage to objects in the country is caused by an entity or person who operates or resides in the country in a legal manner. Damage to the infrastructure by the developed methods involves the assessment of assets by a residual book value. Methods for calculating the amount of environmental damage and compensation for damages (direct or indirect) are currently adopted taking into account the so-called “war coefficients”, that is, costs for environmental damage to the object are calculated according to the methods in force in Ukraine for its citizens and multiplied by a certain coefficient, which may be subject to doubt during the consideration of cases in international courts.

The evaluation of damage to the irrigation and drainage system is constantly carried out by the Ministry of Environmental Protection and Natural Resources along with the State Water Agency using the inventory method, but currently contains only separate/fragmentary estimates of the financial value of the damage to the irrigation and drainage sector as well as water resources that was caused to Ukraine as a result of hostilities. Information about recorded violations in the field of environmental protection and infrastructure is placed on interactive maps [7, 8].

The purpose of the research is to identify the state, scale of destruction, areas of possible damage, and calculate actual damages on reclaimed territories caused by military actions by applying the methodology of using data from remote sensing of the Earth and information technologies.

Research conditions. The research was conducted during 2022-2023 on the lands of the unoccupied part of the territory of Ukraine. The identification of risk zones of potential destruction of reclamation systems and infrastructure was carried out using the information system for supporting decision-making in agriculture, developed at IWPLR [9]. A detailed analysis was carried out for the territory of the Odesa region, the results were scaled to the entire territory of Ukraine.

Research methods and materials. Data on actual damage in the territories were obtained using the ACLED methodology [10] for the period 24.02.2022–31.12.2023 (The Armed Conflict Location & Event Data Project (ACLED) – real-time databases on locations, dates, parties to the conflict, casualties and types of all registered events of political violence and protests around the world, including Ukraine. Evaluation of indirect damage to agriculture on irrigated lands was carried out in 2019–2022, when comparing irrigated massifs by the NDVI index, as well when using statistical methods.

To clarify the direct and indirect losses, the variety of crops was evaluated, and the recognition of crops was verified using the data of remote sensing of the Earth and the Hydrosolution software complex [11].

To evaluate the intensity of agricultural production on irrigated lands, permits for special water use issued for irrigation on the territory of Ukraine were analyzed.

Research results. The reports on damage evaluation in the irrigation and drainage sector are obviously not final, given the ongoing nature of the war and the lack of access to the areas, which temporarily are not controlled by Ukraine. The lack of inventory materials at the state level regarding the state of the irrigation and drainage system, the lack of data on private infarm infrastructure, which is an important part of the lost asset base, also delay damage evaluation. Another cost item not estimated in the described documents is the damage to private irrigation systems, which are generally smaller in size.

At the same time, at the local levels, there is no integrated monitoring of damage evaluation, in particular to water resources, integrated irrigation and drainage systems, and there is no economic assessment of the effects of the war on the production process of agricultural products.

As evidenced by the data of IWPLR [12, 13] and World Bank [13], even before the war started, the irrigation and drainage sector as well as the water management sector had been in a transition period. Some irrigation systems were already unviable, and the irrigated areas of others were significantly reduced. A number of systems were identified for reconstruction and/or modernization. There is a clear need to improve the operation of irrigation and drainage systems and to combine rehabilitation and reconstruction efforts with ongoing institutional reform. The Irrigation and Drainage Strategy sets a medium-term goal of restoring irrigation on the area of 810,000 hectares with possible further expansion to 1.5 million hectares and restoring drainage systems, taking into account 3 million hectares of already drained areas with the possibility of restoring the irrigation functions on such systems in the area of 1 million hectares.

To carry out a rapid visual evaluation of damage to the irrigation and drainage infrastructure, the capabilities of the information system have been expanded this year [14, 15]. The following software solutions were used for data preparation:

- geoinformation system QGIS;
- postgresql database (with PostGIS extension module);
- QGIS geoinformation system;

• Python programming language for developing scripts;

• Pandas, Folium and Leaflet library for data processing and visualization.

To fulfill the task of identifying the destruction areas of reclamation systems, in the current year the work with databases has been supplemented with new possibilities when using the PostGIS module, namely an extension of the PostgreSQL object-relational DBMS. This module helps to store geographic data in the database and facilitates the work with such data. PostGIS includes support for R-Tree/GiST spatial indexes and geodata processing functions.

PostGIS is a geographic information system, or GIS, implemented as an extension to PostgreSQL. GIS enables to store spatial or geographic data, such as points, broken lines, and polygons, perform various operations including efficient searches using them. During the work, the database was connected to QGIS. Layers with pumping stations can serve as an example for analyzing potential damage due to military actions (Fig. 1).

Based on the example of the Odesa region, using the basic information on the pumping stations of reclamation systems and available information about hostilities, explosions, artillery attacks, etc., as a result of Russian aggression in this region, a synthesized image was made, which can be used for a rapid visual evaluation of the impact of military actions on the reclamation systems of the Odesa region. Of course, such information can and should be clarified in the future. A fragment of the inventory database of the reclamation systems as of 2019 is shown in Fig. 2.

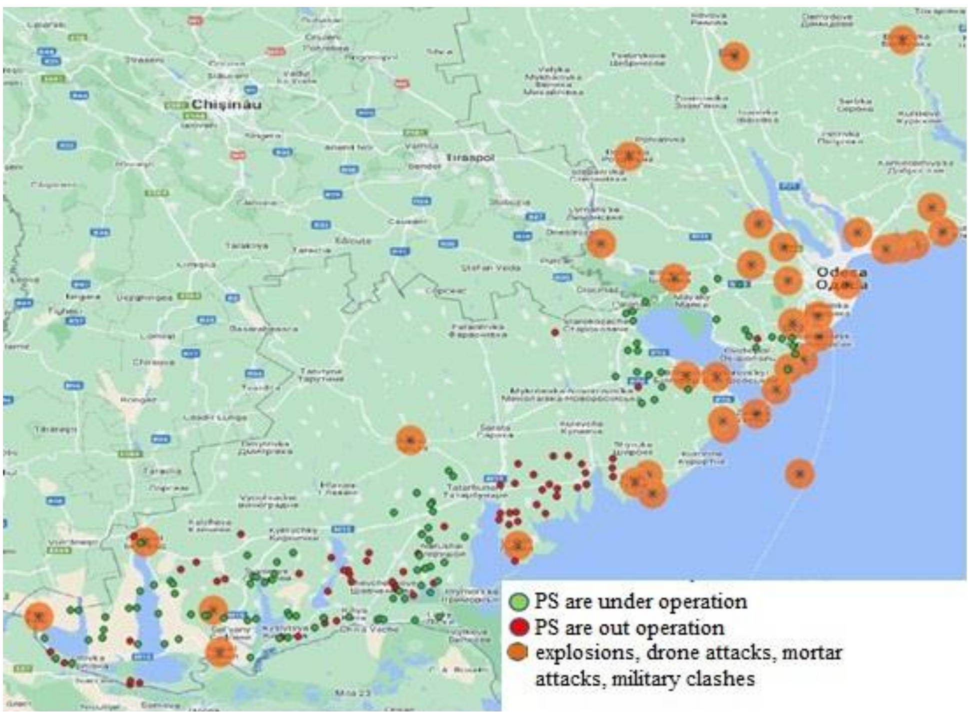

Fig. 1. Identification of risk zones of potential destruction of reclamation systems using the information system

pump_stations — Features Total: 1293, Filtered: 1293, Selected: 0

	id	name pump	nrg_sys	type	area	district	cost	power	name_chane	activity
295	290	НС1 «Перемога»	Котловинська ЗС	підкачуюча	781	Ізмаїльський райо...	0.44	528	оз.Ялпуг	діюча
296	291	НСП «Перемога»	Котловинська ЗС	перекачуюча	781	Ізмаїльський райо...	0.44	800		діюча
297	292	ГНС Новосільська ЗС	Новосільська ЗС	ГНС	1532	Ізмаїльський райо...	0.875	1000	оз.Ялпуг	діюча
298	293	НСП Новосільська ЗС	Новосільська ЗС	перекачуюча	780	Ізмаїльський райо...	0.8	1000		не діюча
299	294	НС1 «Рені»	Ренійська ЗС	перекачуюча	208	Ізмаїльський райо...	0.24	120	р.Дунай	не діюча
300	295	НС2 «Рені»	Ренійська ЗС	перекачуюча	610	Ізмаїльський райо...	0.16	80	р.Дунай	не діюча
301	296	НС1 Долинська ЗС	Долинська ЗС	підкачуюча	1146,3	Ізмаїльський райо...	0.8	1000	оз.Кагул	діюча
302	297	НСП Долинська ЗС	Долинська ЗС	перекачуюча	1146,3	Ізмаїльський райо...	0.7	1000		діюча
303	298	ВНС ОКП «ПрорваСкунда»	Придунайська ЗС	підкачуюча, дренажна	934	Ізмаїльський райо...	1.05	480	р.Дунай	не діюча
304	299	ВНС рпу «Ренійський»	Чудновська ЗС	перекачуюча	383	Ізмаїльський райо...	0.54	410		не діюча
305	300	ГНС Ялпугська ЗС	Ялпугська ЗС	ГНС	3584	Болградський рай...	1.5	2400	оз.Ялпуг	діюча

Fig. 2. A fragment of the inventory database of reclamation systems

After analyzing the territory using the ACLED database, which collects real-time data on the locations, dates, parties to the conflict, casualties and types of all recorded events of political violence and protests worldwide, including Ukraine, the military impacts that can affect the functioning of irrigation and drainage systems are mapped.

The thematic map (Fig. 3) shows the territory of Ukraine with territorial communities and hydrotechnical facilities according to the State Water Agency's inventory data (green symbols on the map). Red symbols indicate military intervention on the territory of Ukraine, which could potentially negatively affect the efficiency of irrigation and drainage systems. Data for the period 02.24.2022 – 02.01.2023 were used to make this map. The damaged infrastructure in the occupied regions was evaluated by the distance to the site of hostilities or explosions recorded in the ACLED database [10].

Using the available information in the database, a rapid evaluation of damage and needs was carried out within the territory controlled by Ukraine. Working and non-working pumping stations, hydrotechnical structures and recorded explosions, drone attacks, mortar attacks, combat clashes, as well as the risk zones of potential destruction of reclamation systems and infrastructure facilities were identified on the map (Fig. 3).

For the period since the beginning of the full-scale invasion (24.02.2022) and till January 31, 2023, the areas were classified by the intensity of hostilities, where the most intense color indicates more than 16,000 documented cases of enemy damage to the territory, namely explosions, drone attacks, mortar attacks, combat clashes, which could potentially affect the operation of irrigation and drainage systems, while the least intense color indicate less than 100 cases. It is obvious that in these areas the intensity of damage to the irrigation and drainage infrastructure at different levels will be distributed accordingly.

Regions were zoned by the intensity of military impacts (Fig. 4), where the color scheme indicates the number of military events within the regions. It is obvious that in these regions the intensity of damage to the irrigation and drainage infrastructure at different levels will be distributed accordingly.

Explosions, remote impacts such as artillery and drone attacks, and direct combat operations in the territories are considered as potential sources of destruction.

The refined methodology for determining the destruction will be based on the automatic determination of the components of reclamation systems, in particular the pumping stations and the reclamation network, which are in the area of negative impacts (explosions, hostilities, etc.), and further actual research of these zones. In fig. 5 there is the ranked infrastructure of the reclamation network in the Odesa region depending on the distance to the places of explosions (from 0 to more than 40 km).

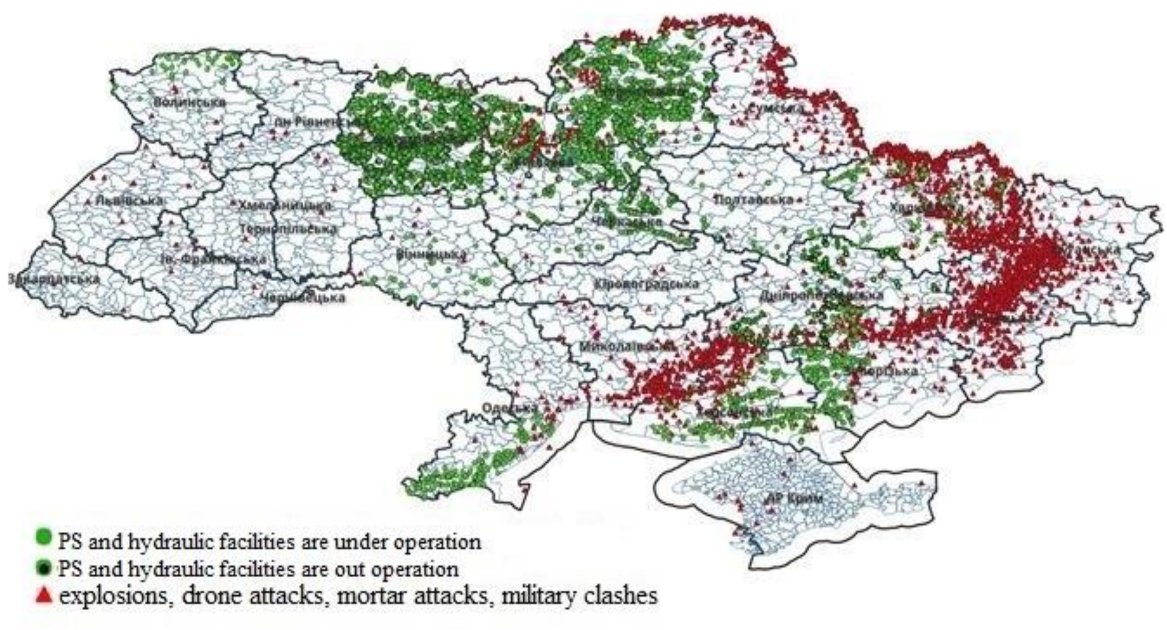

Fig. 3. Synthesized image of the state of reclamation systems in the Odesa region and the risks of the impact of military operations in the period 24.02.2022–31.01.2023

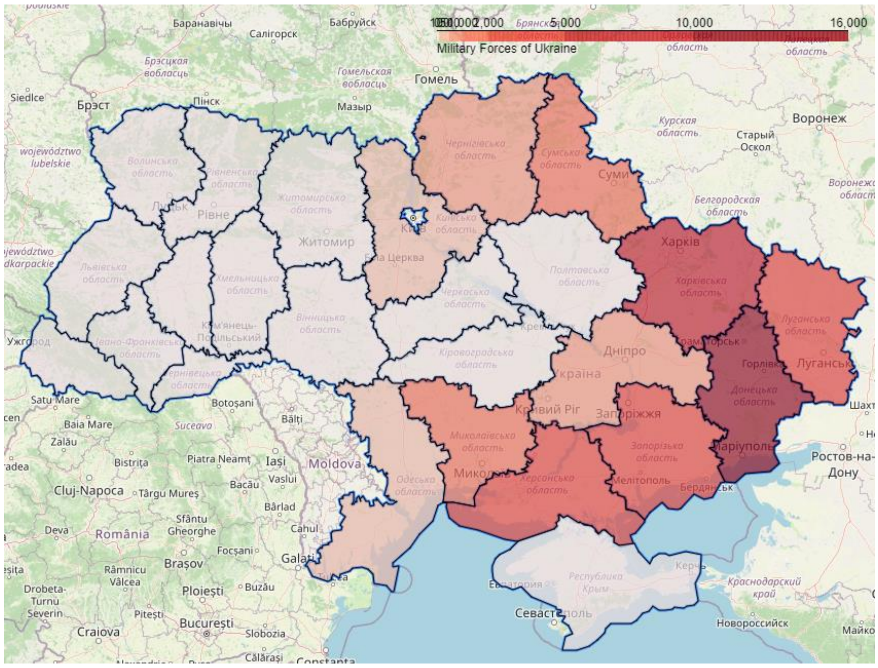

Fig. 4. Zoning of the territory of Ukraine depending on the number of military impacts and the intensity of hostilities

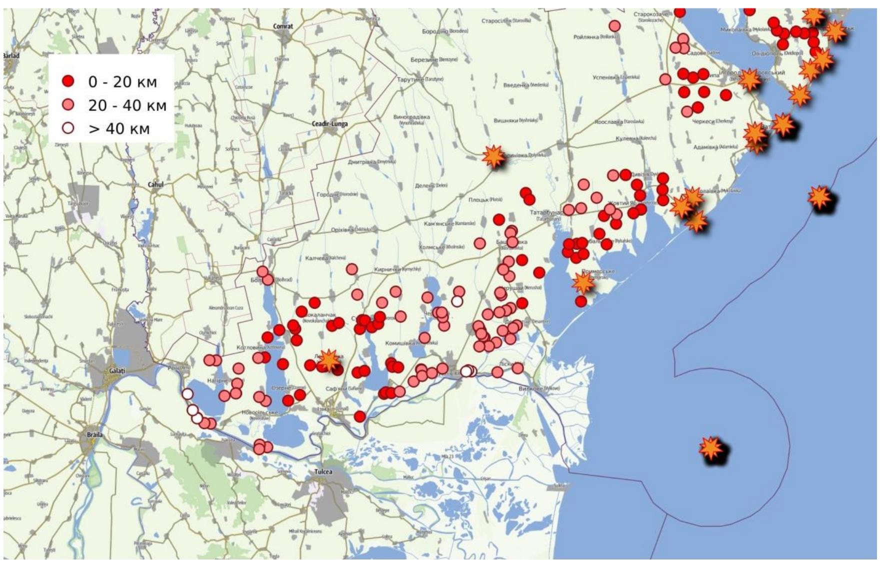

Fig. 5. Identification of potential destruction zones of reclamation systems based on the database of the information system

The identification of potential destruction zones of reclamation systems was carried out on the online platform developed and placed on the IWPLR server [9]. This approach enables to identify the risk zones of potential destruction of reclamation systems and infrastructure objects, to prioritize the restoration of infrastructure across the country and in the Odesa region in particular by the distance to hostilities or places of explosions using the data from constantly updated sources. Remote sensing data, in particular the NDVI index (Normalized Difference Vegetation Index) [16, 17], were used to evaluate the indirect losses and confirm the reduction in production intensity. The irrigated massifs in the Kherson region, in particular in the Chaplynsky district, where field research was already conducted in last years by the authors of this paper [18], were taken as the main area for comparison.

NDVI can be a useful tool for evaluating the condition of vegetation and identifying patterns in its growth, but accurate yield forecasting requires the use of more complex models that combine many factors, including weather conditions, soil quality, agricultural technology, etc. To confirm the fact of a decrease in the intensity of farming in 2022, data on a decrease in the accumulated biomass were used. This change was estimated using the NDVI index, which was specified in the period from 2019 to 2022 for selected irrigated areas in the Kherson region.

Special attention should be paid to the significant decrease in the NDVI index values in the zone where intense hostilities took place. This testifies to the significant impact of military actions on vegetation and agricultural land in this region and emphasizes the need to take measures to restore the agricultural infrastructure and the infrastructure of irrigation systems in this area (Fig. 6).

For a detailed evaluation of damages to agriculture and clarification of direct and indirect damages in terms of changes in the types of cultivated crops, the diversity of crops was evaluated according to the methodology [11]. The study of the accuracy of machine learning algorithms was carried out by the authors from IWPLR and "Hydrosolutions" as part of a joint research (Fig. 7).

Verification of crop recognition using machine learning algorithms was carried out at 287 observation points by the authors. The accuracy of the algorithms was estimated to be 93.4 %.

Based on the developed technologies, it is possible to further specify the amount of direct and indirect damage caused to the irrigation and drainage sector using remote monitoring [19].

The analysis of the concluded contracts for special water use, where irrigation is defined as the purpose of taking water from surface or underground sources, also testifies the losses in the irrigation and drainage sector (Table 1). The set obtained from the open data portal [20] contains a list of issued permits for special water use, including the information provided in the permit form. In particular, the obtained tables included the number, date of issue, status of

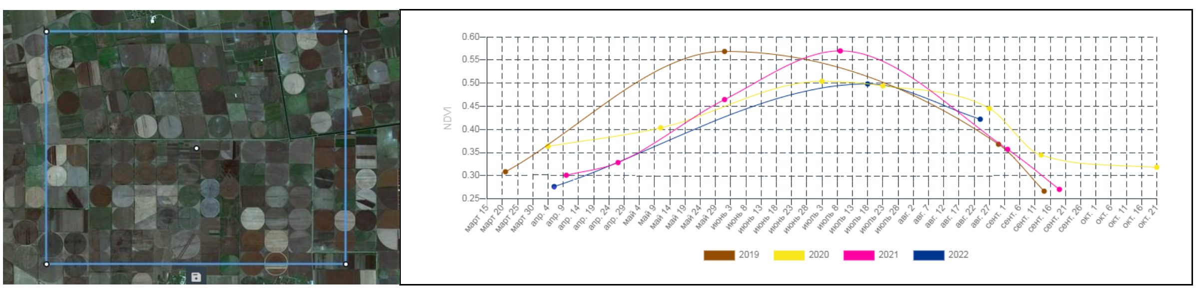

Fig. 6. Decrease in NDVI index values on irrigated massifs of the Chaplynsky district of the Kherson region in 2022

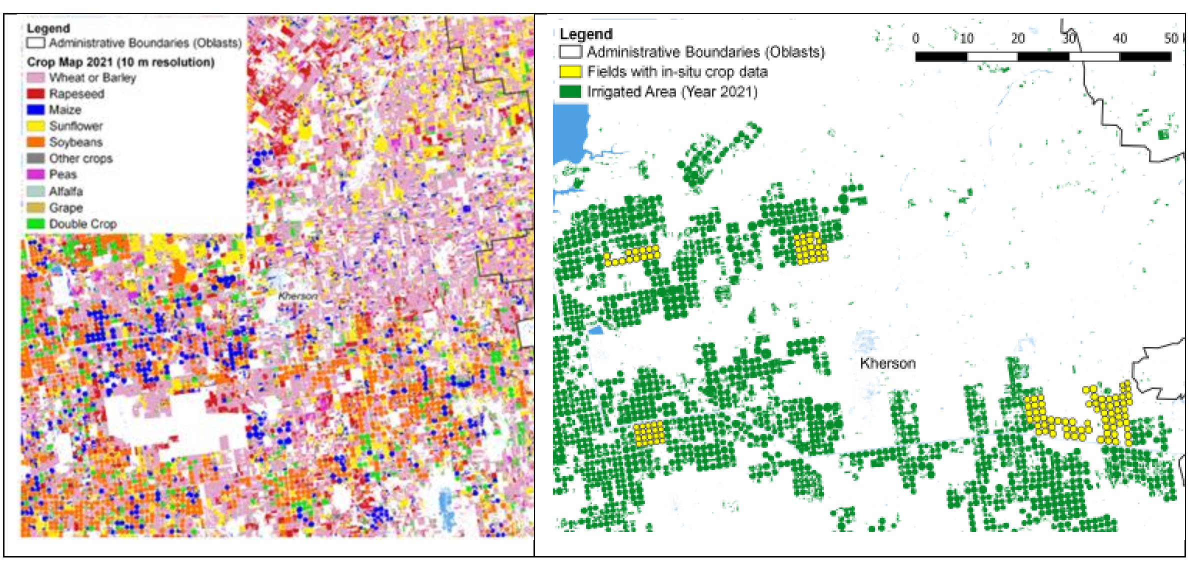

Fig. 7. Verification of the crop recognition system by the authors, "Hydrosolutions", and World Bank

1. The established limit of water intake for irrigation, by the Register of issued permits for special water use in general in Ukraine, thousand m³/year

Regions	2021	2022	2023	2022 compared to 2021
	thousand m³	*thousand m³*	*thousand m³*	*%*
Vinnytska	2531,2	1006,2	50,6	40 %
Volynska	757,2	0		0 %
Dnipropetrovska	63 158,6	6662,5	9,0	11 %
Donetska	4167,7	8183,2		196 %
Zhytomyrska				
Zakarpatska	110,1	177,8		161 %
Zaporizhska	140 975,9	22 951,1		16 %
Ivano-Frankivska	33,1	109,5		331 %
Kyivska	2638,9	246,7	59,8	9 %
Kirovogradska	13 910,3	3308,1	40,7	24 %
Luhanska				
Lvivska	412,8	447,9		108 %
Mykolaivska	79 188,8	10 328,6	1277,0	13 %
Kyiv city				
Odeska	168 697,8	35 794,8		21 %
Poltavska	9750,0	3228,8		33 %
Rivnenska	96,0	405,5		422 %
Sumska	40,8			0 %
Ternopilska	513,0			0 %
Kharkivska	6901,8	148,8		2 %
Khersonska	1 270 640,0	310 600,2		24 %
Khmelnytska	2491,6	723,2		29 %
Cherkaska	19 681,8	17 924,4		91 %
Chernivetska	207,9	70,0		34 %
Chernihivska	688,6			0 %
In total	1 787 593,9	422 317,1	1437,1	24 %

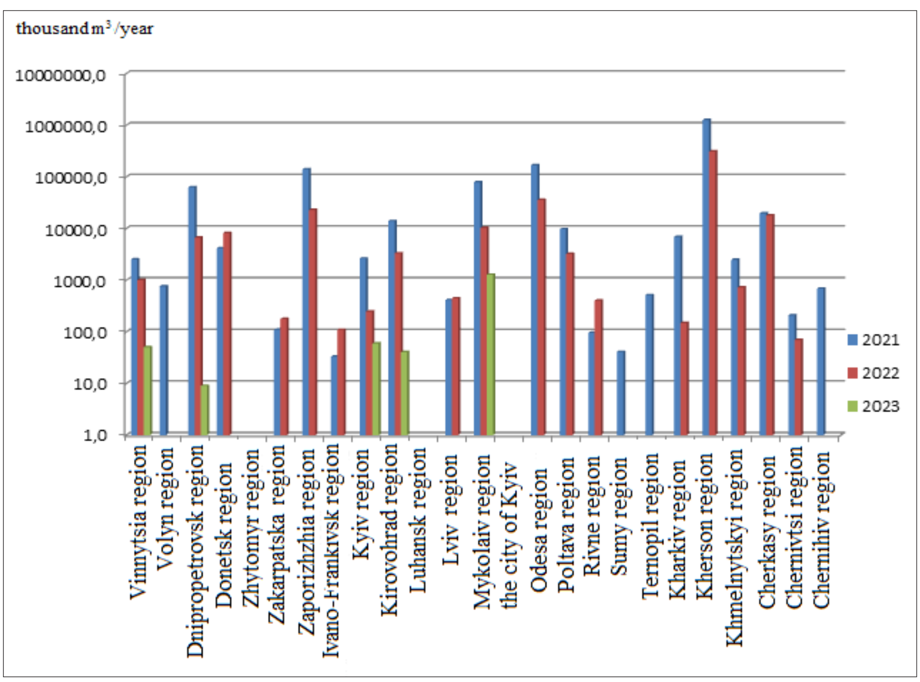

Fig. 8 The established limit for water intake for irrigation needs, according to the register of issued permits for special water use in Ukraine, thousand m³/year

the permit, name and code of the water user's USREOU, validity period of the permit, purpose of water use, limits of water intake and use, volumes of water intake, transfer and discharge by various categories of water users, and others.

The authors analyzed the permits for special water use, where the purpose of water use is specified as "irrigation", issued during the years of 2021–2023, as they indicate the intensity of water use and irrigation intentions.

Since the permitting process is statistically evenly distributed over the years, the number of permits issued annually is roughly the same. With the growth of production on irrigated lands in 2020–2021, the number of issued permits tended to increase. The last column in Table 1 shows the percentage of the actual volume of planned limits for water intake for irrigation needs in thousands of cubic meters by the issued permits in 2022 compared to 2021.

The actual volume of water planned for irrigation in 2022 in total for the country is 24 % of the planned in 2021. That is, the decrease in the intensity of consuming water for irrigation is 76 %. To visualize the data in Table 1, a diagram of the distribution of water intake limits for irrigation by regions for three years was built (Fig. 8).

The data for 2023 are given only until January 31, 2023, so it is appropriate to compare the intensity of obtaining permits in January with previous years (Table 2).

2. Month-by-month comparison of established water intake limits for irrigation needs, according to the register of issued permits for special water use in Ukraine, thousand m^3/year

	January 2021	**January 2022**	**January 2023**
Permit limits, thousand m^3	58427	60637	1437

The analysis of issued permits month-by-month, at the beginning of the year, also testifies the future reduction of water intake for irrigation needs in 2023 and a decrease in the intensity of water use for irrigation.

Discussion. Given the scale and intensity of damage to the infrastructure of reclamation systems as a result of military operations, as well as the difficulty in specifying the actual performance of irrigation and drainage systems, there is a need for re-evaluation and analysis based on data that will be available after the end of hostilities.

Identification of the destruction areas of reclamation systems by the remote sensing data requires a mandatory verification at the local level when performing field surveys. Such studies are particularly relevant, since the correct identification of the areas of the destruction of reclamation systems and reclaimed lands is important in the development of economic assessments, policies and practices aimed at their restoration. It is clear that during the war conflict, an independent monitoring system becomes important, which will allow timely obtaining the information on the state of reclamation systems and infrastructure in war conditions.

In view of the significant scale of damage to the territories, appropriate measures are needed to solve this problem. The complexity of the processes of reclamation systems destruction and deterioration of territory conditions require a combination of various data sources and approaches for proper interpretation.

In conclusion, further areas of research should be the development of a strategy for restoration and improvement of the state of reclamation infrastructure on the principle of better than it was, identification of needs, science-based planning of restoration and international cooperation to ensure the sustainable functioning of reclamation systems.

Conclusions. Large areas of regions, UTCs bordering the territories where the active hostilities take place, are often minded and subject to periodic artillery fire, so there is actual physical destruction of irrigation and drainage infrastructure there. So, there is a need of a rapid expert evaluation of damage to the functionality of the irrigation and drainage infrastructure. The developed methodology for the use of remote sensing data of the Earth and information technologies to identify the areas of possible damage to reclamation infrastructure in the decision support information system in agriculture allows making preliminary conclusions about its malfunction and identifying probable areas of direct destruction and, accordingly, damage. To identify indirect damages, an analysis of received permits for special water use was carried out, which testified that the total amount of water intended for irrigation needs by the issued permits in 2022 amounted to only 23 % compared to 2021. That is, a decrease in the intensity of concluding the contracts for special water use for irrigation needs in 2022 was about 77 %. To visualize the obtained results, mapping and analysis of the studied areas were made by the ACLED methodology. Thematic maps containing the layers of territorial communities and hydrotechnical structures were made based on the data of the State Water Agency's inventory. The maps also show the types of military impacts on the territory of Ukraine that could potentially negatively affect the efficiency of irrigation and drainage systems. To evaluate in details the damages to agriculture, namely to clarify direct and indirect damages to cultivated crops, crop diversity during the cultivation was evaluated and crop recognition was verified using machine learning algorithms, which allows analyzing the change in the structure of crops and profitability. Identification of the destruction areas of reclamation systems by the remote sensing data requires a mandatory verification at the local level when performing field surveys. These measures are particularly relevant, as the correct identification of the destruction areas of reclamation systems and reclaimed lands is important for economic assessments, policies and practices aimed at their restoration.

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ІДЕНТИФІКАЦІЯ ЗОН РУЙНУВАНЬ МЕЛІОРАТИВНИХ СИСТЕМ ТА ОЦІНКА ЗРОШУВАНОГО ЗЕМЛЕРОБСТВА ЗА ДАНИМИ ДЗЗ

Т.В. Матяш[1], канд. техн. наук, Я.О. Бутенко[2], канд. с.-г. наук, А.В. Крученюк[3], А.Ф. Салюк[4], Н.В. Сорока[5], Є.І. Матяш[6]

[1] Інститут водних проблем і меліорації НААН, Київ, Україна;
https://orcid.org/0000-0003-1225-086X; e-mail: t.v.matiash@gmail.com;
[2] Інститут водних проблем і меліорації НААН, Київ, Україна;
https://orcid.org/ 0000-0002-1743-7175; e-mail: iarynabulba@gmail.com;
[3] Інститут водних проблем і меліорації НААН, Київ, Україна;
https://orcid.org/0000-0002-5850-2404; e-mail: anatolkru@gmail.com;
[4] Інститут водних проблем і меліорації НААН, Київ, Україна;
https://orcid.org/0000-0003-3968-1125; e-mail: allasaluk@ukr.net;
[5] Інститут водних проблем і меліорації НААН, Київ, Україна;
https://orcid.org/0000-0003-2868-1832; e-mail: natasha.voda.75@gmail.com;
[6] Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», Київ, Україна;
https://orcid.org/0009-0007-7079-3017; e-mail: liza.mymailbox@gmail.com

Анотація. *У статті проаналізовано результати використання системи підтримки прийняття рішень для ідентифікації зон руйнувань меліоративних систем та проведено оцінювання стану зрошуваного землеробства за даними дистанційного зондування Землі та підтверджено її здатність формувати і надавати користувачеві попередню інформацію про стан меліоративної інфраструктури. Більшість відносно нових і функціонуючих систем зрошення наразі знаходиться поза контролем Уряду України через окупацію Херсонської і Запорізької областей. Зрошувальні та дренажні системи, над якими відновлено контроль і які перебували в зоні безпосередніх бойових дій, опинилися в зруйнованому стані, а підрив окупантами Каховської ГЕС робить неможливим подальше використання зрошувальних систем окупованої і неокупованої частини України, що брали воду безпосередньо з Каховського водосховища.*

Для проведення швидкої візуальної ідентифікації зон руйнувань меліоративних систем для оцінювання збитків зрошувальної і дренажної інфраструктури в 2023 році розширені можливості інформаційної системи, розробленої в ІВПіМ НААН. На прикладі Одеської області на основі базової інформації про насосні станції меліоративних систем та доступної інформації за технологією ACLED про бойові дії, вибухи, артилерійські атаки тощо внаслідок російської агресії сформовано синтезоване зображення, за яким можна провести візуальну оцінку впливу військових дій на меліоративні системи як окремих областей, так і здійснити таку оцінку в межах країни. За інтенсивністю військових впливів за допомогою інформаційної системи проведене зонування областей за кількістю військових впливів і очікуваного ушкодження інфраструктури систем зрошення і дренажу. Оцінку зон непрямих збитків проведено з використанням даних дистанційного зондування за індексом NDVI, який свідчить про зниження накопичення біомаси на території зрошувальних систем, прогноз подальшого використання зрошуваних земель наведено на основі статистичного аналізу даних про укладання договорів на спецводокористування, який засвідчив зниження в чотири рази обсягів води, запланованих для використання в 2022 році.

Результати можуть бути використані для проведення оцінки збитків, нанесених Україні в результаті воєнних дій та підтвердження руйнівного впливу війни на сектори зрошення і дренажу.

Ключові слова: *дистанційне зондування Землі, дощування, інформаційна система, збитки, управління зрошенням, спецводокористування, зрошення*

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PRINCIPLES OF CALCULATIONS AND ARRANGEMENT OF LOCAL DRAINAGE SYSTEMS IN PRIVATE BUILDING TERRITORIES

O.L. Shevchenko[1], Doctor of Geological Science, A.O. Streltsov[2], Ph.D. student

[1] Ukrainian Hydrometeorological Institute SSES of Ukraine and NAS of Ukraine;
https://orcid.org/0000-0002-5791-5354; e-mail: shevch62@gmail.com;
[2] Institute of Geological Science of NAS of Ukraine;
https://orcid.org/0009-0008-5394-8731; e-mail: streltsov.kiev.ua@gmail.com

Abstract. *Abnormally heavy rains in the first two spring months of 2023 revealed the unpreparedness and lack of protection of many settlements in the Kyiv region from excessive moisture and inundation. Among them, is Novi Petrivtsi village, where the natural conditions for surface runoff and precipitation infiltration (lack of visible surface slopes and poorly permeable cover sediments) are unfavourable and significantly complicated by buildings, and a network of highways. The long-term retention of water on the surface, the rise of groundwater levels, and the layered structure of the upper part of the geological section provide grounds for the use of combined local drainage systems with compliance with drainage standards of at least 3.0 m. Since the high density of buildings often does not allow for contour drainage around residential buildings, it is necessary to lay single-line horizontal drainage to a greater depth than for a conventional contour drainage of 3.5 meters or more. However, the lack of roadside ditches and other water intakes and means of orderly drainage do not allow homestead drainage systems to work as efficiently as possible. This requires the creation of an orderly system of water intakes (trenches and closed collectors) on the scale of the village. Foreign experience convinces that the rational planning of such systems is possible under the conditions of establishing the character of rainfall distribution with a resolution of 1–5 minutes in time and a step of 500 m across the area. Meteorological radar is used to record radar images of rain and study its intensity. An effective solution to the water drainage problem is impossible without detailed engineering and geological investigations. Due to them, litho-facies inhomogeneities in the aeration zone and water-saturated stratum, which lead to the retention and support of groundwater, were discovered in the local area. Taking into account the spatial boundaries of these engineering and geological elements allow drainage more efficiently. Drainage capacity is substantiated by forecasts of changes in the maximum amount of precipitation per day and two days in a row. Due calculating the drainage capacity, it should be taken into account that the maximum amount of precipitation in the future period will have a guarantee of 0.5–2.0 % less than the actual maximum values. In the calculation part, the main attention is paid to the selection of equations for determining the width of influence of a single horizontal drain. Five formulas have been selected that can be used to solve similar problems. The time of onset of the established mode of operation of a single drain was calculated. Future research should focus on the collection of high-resolution rainfall and local urban runoff data, as well as the implementation of urban drainage models.*

Key words: *drainage, groundwater level, flooding, private construction, inundating, precipitation, provision, sewerage, climate change*

Relevance of research. The high density of private buildings in small settlements of the Kyiv agglomeration, and the unpredictability of weather anomalies are increasingly exacerbating the problems associated with the harmful effects of water and forcing the search for optimal means of countering flooding and inundation.

There is a noticeable increase in the amount of precipitation associated with the beginning of the high-water cycle after the end of the abnormally low water cycle of 2009–2020. According to the forecast scenarios of changes in the amount of precipitation in the third decade of the 21st century, there will be an increase in the amount of precipitation in the winter (according to three executed scenarios) and spring (two out of three scenarios) seasons in the greater territory of Ukraine [19]. Moreover, the increase in the amount of spring precipitation is determined by the frequency of heavy daily precipitation. Compared to the period of 2001–2010, the maximum precipitation of the spring season of the 20s (the third decade) will increase by 45–92 mm (according to the three executed scenarios).

Although it is doubtful that such an increase is justified in the Ukrainian Polissia zone, it has been recorded that the precipitation in April 2023 at the Vyshhorod weather station (68.6 mm) had a rather low coverage of 13.5 % and was higher than the average values of 2001–2010 by 31.5 mm (85 %), and in 2011–2020 by 39.6 mm (137 % of the average value for the compared period). Since the maximum value of spring precipitation for the third decade has probably not yet been reached, it can expect an increase in the amount of spring precipitation until 2030 and an increase in the risks of flooding and inundation of poorly drained areas. The main problem will be related to the significant unevenness of precipitation when short-term showers with a supply of less than 10 % will create a large load on sewerage systems, which will force them to increase their carrying capacity. This prompts the search for ways to quickly drain a large amount of water in a short period of time.

Analysis of recent research and publications. A review of the current state of rainwater drainage systems in the territories of the newest private buildings in Ukraine gives the impression of neglecting the problem of centralized drainage. The attitude to this issue in Ukraine is especially contrasted with the rainwater sewerage control system in settlements abroad [24, 29]. As a result of the artificial overlapping of the natural surface, small urban and village catchment basins are characterized by fast runoff processes and a short response time to precipitation. Due to this, they are extremely sensitive to the spatial and temporal variability of precipitation (in cities, this variability is significant even on a small scale) [26, 27]. The development of urban construction leads to the planning and overlapping of zones of the natural flow of excess stormwater [24]. In addition, runoff problems in urbanized areas are created due to the clogging of storm drains, collectors, and hidden riverbeds. Separate studies demonstrate an increase in the amount of precipitation in large urban agglomerations, compared to their periphery, which may be associated with raised evaporation of moisture from impermeable surfaces due to increased temperature and boosted updrafts [25]. Services that control stormwater drainage have concluded that high-resolution precipitation information is needed to manage urban runoff processes [28]. Increasing the temporal resolution of rainfall has a greater impact on the results of hydrodynamic modelling than increasing the *spatial* resolution [29]. A theoretical study by Schilling (1991) suggests that rainfall data with a resolution of at least 1–5 min in time and 1 km in distance should be used for urban drainage modelling. Bern et al. (2004) investigated the temporal and spatial scales of various urban catchments and established the required temporal and spatial resolution of rain measurements for urban hydrological applications. The spatio-temporal resolution proposed by [30] (1–5 min in time and 100–500 m in space) is used for detailed modelling of sewage systems in European cities. Using a geostatistical approach, an analysis of variograms of non-zero precipitation is performed. Periods of rain are recorded by the Treier meteorological radar, which provides radar images of rain with a high level of spatial resolution (250 × 250 m) and instantaneous temporal resolution [26]. In addition, the UKCEH Gridded Estimates of Areal Rainfall (CEH-GEAR) at 1 km resolution is available for many countries, particularly the UK.

In Ukraine, more attention is paid to the flooding of settlements as a result of the load from buildings, the crossing and support of natural streams by underground structures, operational and emergency losses of water from urban water supply and sewage networks, etc. [14, 20, 22, 23].

The main task of drainage systems in flooded built-up areas is to ensure the necessary reduction in the level of groundwater (LGW), which is determined by the deepening of basements, communications, and other underground structures. To avoid flooding of buildings in populated areas, drainage should intercept and divert at least 45 % of the amount of precipitation [24]. When protecting buried structures from underground water, the lowered LGW should be below the base of these structures at least to the height of the capillary rise of water in draining soils [13]. The type of drainage that can be applied is horizontal, vertical, or combined, including radial, depending mainly on the lithological composition and structure of the drained soils, and the degree of density and character of the building [15]. From experience, on draining areas with poorly permeable soils on the surface, collector-drainage systems are well known [6], and draining poorly permeable rocks at depth, vacuum drainages are effective, the water-receiving part of which is sealed and a vacuum is maintained in it with using of a vacuum pump, which allows the removal of only free, but also bound (capillary) moisture. The discharge of drainage water is carried out into open watercourses, reservoirs, ditches, and in their absence into absorbing wells and boreholes or into water receivers (pre-chambers) of pumping stations through dead pipelines [2–4]. The optimal option in terms of economic indicators is when water flows by gravity to the water intake. However, if the settlement is located on a lower terrain, forced pumping of water is resorted to.

Although the tasks of the drainage system on agricultural land and in built-up areas are different, the requirement for optimization of drainage parameters is common, which consists of determining such values for which capital investments in construction would be minimal, while ensuring that the groundwater level is below critical depths and norms drying [7, 9]. The approaches and principles of drainage calculation are also similar. In one case, the load on the drainage is formed as a result of infiltration of atmospheric precipitation, irrigation water, and filtration losses from channels (for irrigation systems) or infiltration of precipitation and lateral inflow (for drainage systems), in the other atmospheric precipitation, lateral inflow from the higher territory and possible losses from sewage facilities and septic tanks.

Therefore, for the calculations of local sewerage systems, it is possible to rely on the fundamental works on determining the optimal parameters of the operation of horizontal and vertical drains [1, 10, 11, 13]. The principles of modelling drainage systems formulated by Polyakov [12], allow the development of reliable algorithms for drainage engineering calculations. The method of calculating water inflow to horizontal drainage proposed in [8] is quite simple and therefore attractive.

However, despite the high level of existing methods for determining the main parameters of drainage and a large number of calculation options [7, 8, 10–13], which is associated with significant variability of hydrogeological conditions and a large list of agricultural and technical tasks, there is a lack of rational approaches to calculation substantiation of the method of drainage of small built-up areas, where the arrangement of contour drainage is impossible. For this, in most cases, it is necessary to use the formulas for single drains, while the possibility of the existence of drainage in neighboring areas should be taken into account, which is mostly designed without taking into account the combined operation (superimposed action of the drainage).

When substantiating and calculating drainage, special attention is paid to additional infiltration feeding of groundwater. The intensity of this feeding in the Kyiv region is quite high and, in some areas, reaches 10^{-2} m/day, on average it ranges from $5 \cdot 10^{-3}$ to $5 \cdot 10^{-4}$ m/day [5, 21], increasing significantly during the spring snow melting. However, in Ukraine, there is a complete absence of the application of a geostatistical approach using meteorological radars, which would ensure the differentiation of the territory of populated areas by the frequency of maximums and amounts of precipitation and would allow for the rational distribution of rainwater drainage systems.

The purpose of the research is to select the optimal calculation models and constructive and technological solutions for local drainage systems in modern conditions of climate change (taking into account changes in the amount of precipitation) in the territories of private development.

Asking the question and justifying the research methodology. It would seem that the Novi Petrivtsi village in Kyiv region, located much above the level of the Dnipro River, has no prerequisites for crises during high floods and high waters. However, the naturally low drainage in the greater part of its territory, associated with the uneven topography and poorly permeable sediments from the surface, is currently significantly complicated by dense buildings and the lack of an orderly drainage system. In the yard of a private house on Nova Kyivska Street is periodic flooding of basements with groundwater and retention of meltwater and rainwater on the surface (Fig. 1). There is no natural open drain within a radius of at least 1.0 km from the site. There are also no artificial drainage ditches along the roads that pass from the southwest and northeast of the house.

Briefly will consider the main characteristics of natural conditions, which are important from the point of view of identifying the causes of flooding and calculating drainage parameters.

Characteristics of the research object. The research territory is located on the high (watershed) territory of the right bank of the Kyiv Reservoir. The surface is very poorly drained, and flat. The main drain of the Dnipro River is located approximately 3.2 km to the east. In terms of geomorphology, the area belongs to the moraine-zandr plain, which is connected with the distribution of heavy glacial loams. Only loose sedimentary rocks are present in the geological structure of the overburden. Up to a depth of at least 8.0 m, they are represented by modern, upper- and middleneopleistocene eolian-diluvial, as well as moraine and hydroglacial light sandy loams with the inclusion of pebbles and gravel of crystalline rocks (Fig. 2) and supramoraine and submoraine fluvioglacial sands (the depth of the sole is about 9.0–9.5 m). Below are Pliocene eluvial-diluvial brown clays, which gradually turn into variegated Miocene clays, with a total

Fig. 1. Inundation roads (a) and yards (b) in Novi Petrivtsi village, April 2023

thickness of 18–22 m [16, 21]. Of course, in the zone of draining influence of the Dnipro River, the aquifers of the Neogene and Paleogene do not have significant pressure. Therefore, the flow from the bottom to the first aquifer from the surface of the pressure less aquifer can be neglected.

The level of groundwater (LGW) at the time of searches (end of October to the beginning of November) was 1.95–2.15 m from the surface. In wet periods of the year, the LGW can rise by an additional 1.0 m (to a depth of 0.9–1.1 m from the surface). After reconnaissance and a thorough study of the engineering-geological and hydrogeological conditions of the site, it was possible to establish ***the main reasons for water retention and flooding of the territory:***

1) climatic conditions – the territory belongs to the zone of sufficient moisture (in the case of poorly permeable cover soils, a layer of runoff is formed on the surface or water is retained in micro depressions of the terrain);

2) the flat topography causes very weak natural drainage of surface sediments; the presence of an elevation in the central part of the site and significant built-up of the territory significantly complicate the runoff of meltwater and rainwater;

3) lack of channelized drainage of stormwater runoff and meltwater runoff, which, after flowing from the roofs of 4 buildings and artificial surfaces (tiles), is localized in depressions or enters the surface of lawns and gardens;

4) occurrence of poorly permeable sediments from the surface, whereby a layer of fluvioglacial

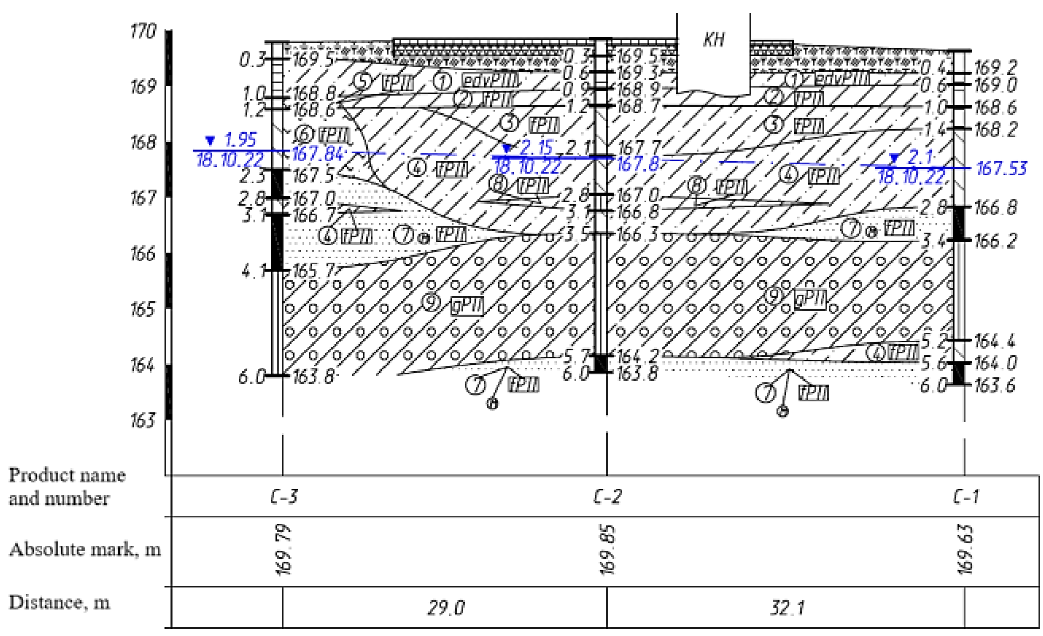

Fig. 2. Engineering-geological section along a private area in Novi-Petrivtsi village for drainage design

loam builds up power inversely to the general, very weak slope of the surface and the direction of the flow of groundwater (toward the Dnipro River), which contributes to the local support of the local flow of perched, which is seasonal (during the melting of snow) is formed close to the surface;

5) wedging of a layer of fluvioglacial sands in the middle part of the section and the area with its replacement by less permeable sandy loam with a layer of light loam, which creates filtration resistance and groundwater support downstream, as evidenced by a significant *decrease in the flow gradient* in the upper part (I = 0.00137) compared to the lower I = 0.0084 on the northeastern edge of the site;

6) the shallow location of the local relative aquifer – a layer of moraine loams – at an average depth of 3.5 m with its roof approaching the surface in the direction of the groundwater flow, which also slows down their natural filtration downstream;

7) a filtration well in the upper part of the natural flow of groundwater creates an additional dome of water spreading (as evidenced by a higher LGW), which is slowly activated due to the peculiarities of the geological structure of the upper part of the section and weak drainage.

In addition, pressure feeding of the upper water-saturated layer of sand and sandy loam is possible due to the formation of its pressure in the submoren sand layer, which will reduce the efficiency of horizontal drainage. Undoubtedly, the choice of water-lowering method will also be influenced by the lack of possibility of discharge of drainage water outside the site.

If the fight against flooding and / or inundation is carried out at the level of an entire settlement, then in each specific case, factors are ranked, which allows for the development of generalized recommendations for the prevention or elimination of inundation [17]. At the same time, it is necessary to be guided by *the principle of maximum use and even return of the natural conditions of the runoff,* which have been changed as a result of economic activity, in certain areas of the territory. However, in the built-up area, it can only use the natural landscape conditions to the maximum to ensure gravity drainage of excess water, and geological and hydrogeological conditions to transfer excess moisture into aquifers with better collector properties and accelerated unloading.

Technological solutions should be aimed at ensuring the drainage of rain and melt runoff, lateral inflow of groundwater, and lowering their level. To eliminate the causes of flooding according to 2 and 3, it is expedient to ensure the drainage of surface rain and melt runoff from the roofs of buildings through the storm collector to the absorbing well; and according to 4 and 5 lay two links of linear horizontal drainage with discharge into the intake borehole.

Results and their discussion. At the beginning, it is advisable to calculate the total load on the receiving drainage collector and, accordingly, determine its hydraulic parameters.

Assessment of the load on the drainage (*Fd,* m^3/m^2) allows establishing the drainage flow module *qp*, m^3/day from 1 m^2 the main indicator of the efficiency of the drainage [7], which combines hydraulic and filtration calculations and can defined as:

$$q_p = Fd / t, \quad (1)$$

where *t* is the duration of the settlement period, days. *Fd* can be determined by the formula modified for local drainage on a built-up plot with a garden when the collector combines the functions of sewerage, drainage, and storm (rain) drainage:

$$Fd = V_P + V_e \pm V_Y \pm V_{ver}, \quad (2)$$

where V_P is the infiltration supply of groundwater by atmospheric precipitation; V_Y is the difference between inflow (from building roofs) and outflow of surface water, m^3; V_e is water loss from the septic tank, m^3; V_{ver} is the vertical water exchange of the balance layer with the groundwater located below, m^3, which can be neglected under the given conditions.

First, the total maximum load on the drainage is determined due to infiltration on the open surface, rain and melt runoff from roofs and artificially covered surface, as well as losses from the filtration well.

The capacity of drainage collectors and the speed of water movement in them is calculated or selected according to the formulas of uniform water movement and when the pipes are completely filled can be calculated according to the Chesy formula: *Q* = *S V*, where

$$S = \frac{\pi \cdot d^2}{4}, \quad (3)$$

The Chesy coefficient (*C*) for drainage pipes is taken according to the formula:

$$C = \frac{70\sqrt{R}}{n' + \sqrt{R}}, \quad (4)$$

where $$R = \frac{\pi \cdot r^2}{2\pi \cdot r} = \frac{d}{4}, \quad (5)$$

If assumes a collector diameter of 110 mm, then the desired flow rate in the pipe will be equal to 3.33 l/s (at a roughness of 0.08). In a day, at such costs, the drainage can pass 287 m^3, which fully satisfies the need to remove the maximum possible daily load on the drainage of 167.0 m^3/day (corresponds to a provision of 0.1 %). Most of the components of the total amount of water to be diverted are predictable. The largest volumes are caused by water consumption and its removal through the sewer to the septic tank, from which the water enters the groundwater through the filtration well. That is, the greatest load will be on the closed part of the drainage. Obviously, to reduce this load, surface runoff should be intercepted and diverted through a separate rain collector.

Calculations of stormwater sewerage taking into account climatic changes. As is known, in built-up areas the percentage of surface runoff in the water balance increases (the share of infiltration decreases accordingly) compared to natural surfaces. The collector should be calculated for costs that will be higher by 4.4 % than the actual spring precipitation for the period 2001–2010 (according to forecasts), or the actual maximum precipitation of the summer season (according to all variants of the forecasts, summer precipitation in the third and fourth decades is not will increase, and most likely will decrease [19]). In fact, in 2023, frequent and significant precipitation in April led to surface flooding and inundation of buildings. According to the Vyshhorod weather station, the amount of precipitation for this month was 68.6 mm, which, according to the analysis of data from 1971 (53 values), corresponds to a supply of 14.4 %. The coverage for each member of the series was calculated according to the equation:

$$P = \frac{m - 0,3}{n + 0,4} 100\%, \quad (6)$$

where m is the ordinal number of a member of the series of studied values, arranged in decreasing order; n is the total number of members of the series.

Since the empirical curve ends at a value of 122.3 mm, which corresponds to a coverage of 1.3 %, a theoretical curve was constructed, according to which a coverage of 1 % corresponds to a sum of precipitation of 131 mm. However, more important is the maximum amount of daily precipitation, as well as precipitation during two consecutive days. The first value for April in the period 1976–2023 is 42 mm (1987) (P = 1.4 %), for the period 2001–2010 is 22,3 mm (P = 13.8 %), the second respectively, 73 mm (1976) and 25.2 mm (P = 20 %). Precipitation with a 10 % guarantee will amount to 28.3 and 38.7 mm, respectively. According to forecasts, these values are expected to increase to 29.6 and 39.2 mm, which should be foreseen in the projects. The maximum daily precipitation for April 2023 amounted to 32.2 mm (P = 7.6 %), which significantly exceeds the forecast (increase by 4.4 %) relative to the maximum value of 2001–2010. In fact, the maximum daily precipitation at the beginning increased by 44 % in the third decade.

The maximum daily amount of precipitation in the warm period of 2001–2010 consists of 62.9 mm (May 2002), which corresponds to a coverage of 6.7 %. Since these are precipitations of the spring period, they can increase by 4.4 %, that is, reach 65.7 mm, which corresponds to 6.1 % of security. Therefore, the storm collector should be calculated for costs derived from the amount of precipitation, which corresponds to a provision of no more than 5 %.

According to the results of the wavelet analysis of daily precipitation for the period of 1976–2002, a significant increase in the frequency of minimum and maximum daily precipitation was established: before 1991, the maxima alternated with a frequency of about 10–11 years, and after 1991 with a frequency of 5.4–5.5 years.

According to the dynamics of precipitation recorded at the Kyiv weather station, the largest amount of precipitation in September-October, when 34–40 mm can fall per day. The biggest risk is heavy precipitation for 2 days in a row. Such cases have been recorded in Vyshhorod weather station for the past 12 years in June and August, in particular, on June 26 and 27, 2011, 42.1 and 61.8 mm fell, respectively, and on August 13 and 14, 2012 of 48.9 mm, respectively and 38.5 mm of precipitation, which confirms the validity of the forecasts made in 2010 [11]. Based on the maximum daily precipitation of 62 mm, the consumption will be 21.2 m^3/day.

It should be noted that the calculations of rainfall are necessary not so much to justify the diameter of the collector (the set of standard pipe diameters is limited and a diameter of 110 mm with a margin meets the needs of local drainage), but to account for the total load on the collector network of the built-up area of the village. A pipe with a diameter of 110 mm at a slope of its laying of 0.002 and working with a full cross-section at a roughness of n = 0.1 provides a throughput of 3.08 l/s, which fully satisfies the requirements for the removal of high storm runoff.

Calculations of closed horizontal drainage. Since the drain must be laid from the wall (foundation) at a distance exceeding the minimum L_{min}, formula [1] should be used to determine it:

$$L_{min} = l_f + l_d / 2 + \Delta h / tg\varphi, \qquad (7)$$

where l_f is the protrusion (lower extension) of the foundation, l_d is the width of the drainage trench, φ° is the angle of internal friction of the drained soil; Δh is the vertical distance from the base of the foundation to the horizontal axis of the tubular drain.

The determined distance was 3.15 m, which meets the necessary conditions.

Taking into account the *area of the required drain*, it can determine the total costs for a perfect drain (in this case, 200.5 m^3/day). At the first variant of an imperfect drain, they amount to 113 m^3/day, which also satisfies the hydraulic parameters of linear drainage (3.33–3.77 l/s).

The most important indicator of the efficiency of the drainage is the width of the spreading zone of water lowering from a horizontal narrow drain which can be approximately calculated using the formula for the period of the unstable filtration regime for the time of the formation of the depression funnel:

$$L = H\sqrt{\frac{k}{2\omega}\left(1 - \exp\left(-\frac{6\omega \cdot t}{\mu H}\right)\right)}, \qquad (8)$$

where t is draining operation time, day; ω is infiltration, m/day; k is filtration coefficient, m/day; μ is the water yield coefficient.

If the infiltration supply will be 0.01 m/day, and the actual pressure $H = 7.5$ m (from the water table), then according to formula (8), the width of the water lowering zone will be about 23.6 m, which is typical for the values of the inter-drain distances for similar hydrogeological conditions. At the same time, the drainage flow module can be about 0.03 l/s per ha. That is, in one direction from the drain, the water lowering extends for almost 12 m. The practically identical value of 24 m is obtained from equation (9), which does not take into account infiltration over the area, which corresponds well to the conditions of construction and artificial covering of the surface and drainage of rain runoff by a separate overflow collector:

$$L = 1.73\sqrt{\frac{kHt}{\mu}}. \qquad (9)$$

The total maximum distance to which the action of the drain should extend ensuring the drainage rate (2.5 m) should be 14.55 m.

It should be taken into account that although the zone of influence of a single drain can be greater than the inter-drain distance under the same parameters of two parallel drains, the reduced LGW at a distance of $L_d/2$ from a single drain will be higher than under the influence of two drains.

In order to estimate the total distance over which the influence of the drain extends in one direction, we determine the dynamics of the spread of the influence and the limit of this influence (where the reduction of LGW becomes infinitely small) on the tenth day of operation of the drain in a quasi-steady (or unstable) mode using the formula of I. N. Pavlovtsia:

$$L_t = 3.16 \cdot \sqrt{a_y \cdot t}, \qquad (10)$$

where
$$a_y = \frac{k(3h_L + h_\partial)}{4\mu}, \qquad (11)$$

According to calculations, at $h_L = 1.7$ m (natural LGW), $h_\partial = 0.5$ m – water pressure above the drain, the coefficient of conductivity a_y will be equal to 38 m^2/day, and the influence of the drain in one direction will extend to a distance of 61.6 m, and with compliance of drainage norm by 20 m (Fig. 3).

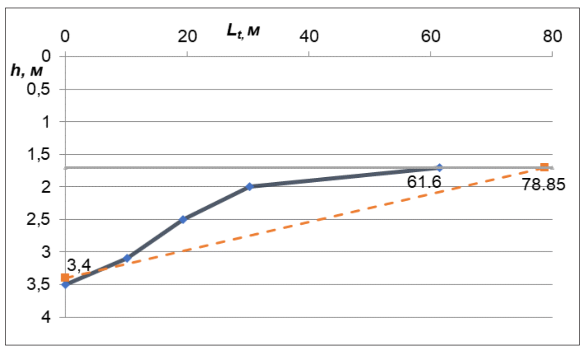

Fig. 3. Spread of water lowering (pressure line) in one direction from the drain on the 10th day under an unstable regime (solid line) and on the 17th–18th day under a stable regime (when the drain is operating in full section) (dashed line); the horizontal line of 1.7 m is the natural level from the surface at the edge of the drain

Since the construction area is located practically on a watershed with a slight slope of the soil flow and the absence of an obvious contour of the area of supply and pressure formation, the unstable mode of filtration in the zone of influence of the drain can continue for a long time. If the unstable regime continues for up to 30 days, the influence of the drain can spread to 105–106 m.

Let's assume that after a certain time, a stable filtering regime will be established and the contours of the depression funnel and the zone of influence of the drain will stabilize. The width of the influence zone in one direction from the horizontal drain can be roughly calculated using the equation:

$$L_д = \sqrt{\frac{k(H_L^2 - h_д^2)}{2 \cdot w}}, \quad (12)$$

where k is the filtration coefficient (2.31 m/day); t_P is the natural pressure from the aquifer at the edge of the drain, or the natural capacity of the aquifer for the depth of laying the drain 3.5 m and LGW = 1.7 m equals 1.8 m; $h_д$ – pressure in the drain from the water resistance (taken to be equal to 0.2 m); w – infiltration supply (about 0.0006 m/day). Hence, $L_д$ under the established filtration regime will be equal to 78.5 m. Provided that the pressure does not exceed the limits of the drain, i.e. $h_d = 0.1$ m, $L_д$ will change insignificantly, increasing only to 78.85 m (Fig. 3), the zone with compliance with the drainage norm, will be about 40 m. Based on the values of $L_д$, which can be obtained from equation (13), it can be assumed that the steady state will come on the 17th–18th day of operation of the drain.

$$L_д = 2 \cdot \sqrt{\frac{k t_p h_1 h_2}{\mu(h_1 - h_2 \alpha) + P - e}}, \quad (13)$$

where k is the filtration coefficient, m/day; t_p is the estimated (or normative) time for the reduction of LGW to the drainage norm h_n at a distance of $L_д/2$ from the drain. For conditions when the main volume of water comes from the filtration well, which is located next to the septic tank, t_p is taken equal to 2 days; $h_1 = h - h_{\min}$, where $h_{\min}$ is the depth of LGW from the surface during a typical wet period or under natural flooding conditions, taken as equal to 1.5 m; $h_2 = h - h_n$.

Therefore, in order to prevent the flooding of the plot with a residential building, it is necessary to lay a single-line horizontal drainage to a depth of at least 3.5 m, which makes it conditionally perfect. It is necessary to maintain a distance from the foundation of the house to the drain of 3.0–3.15 m. This drainage link (D-1) is laid with a slope of at least 0.002 and extends to the absorption well (Fig. 4), crossing the area of natural support of the soil flow (due to facial replacement, see Fig. 2).

The fourth and fifth causes of flooding are eliminated due to the arrangement of the closed tubular drain D-1 and the absorbing borehole. The 6.3 m deep well is drilled to the lower water-saturated sand layer with better reservoir properties than the wedged upper layer. It is equipped with a pump to ensure the removal of excess water during peak periods of rain and snowmelt in the event of a rise in the LGW above 2.0 m (to eliminate the cause of flooding № 6). Its purpose is to divert water coming from the horizontal drain and reduce the pressure level of the sub-pressure horizon in the submoren sands. Drainage of the pumped water through the pipeline (T-1) to the rear edge of the site with distribution over the garden area is carried out using 5 underground sprinkler pipes (Fig. 5) with a diameter of 40 mm.

The necessity for the equipment of an absorbing inspection well (K) in the rear part of

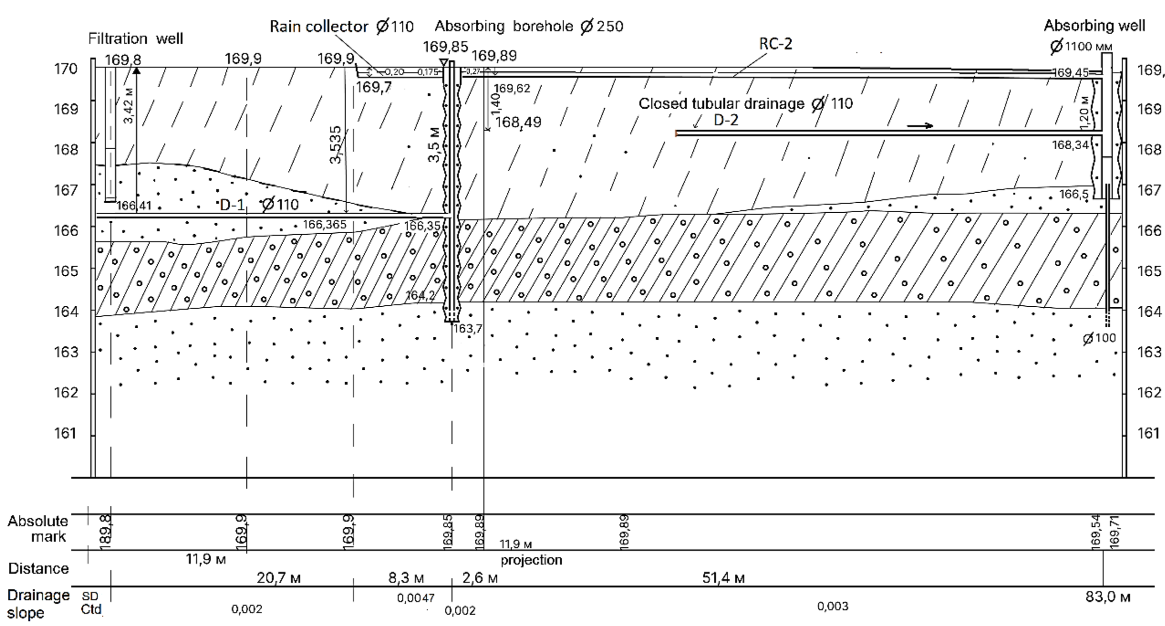

Fig. 4. Section along the plot of a private building with removal of drainage means

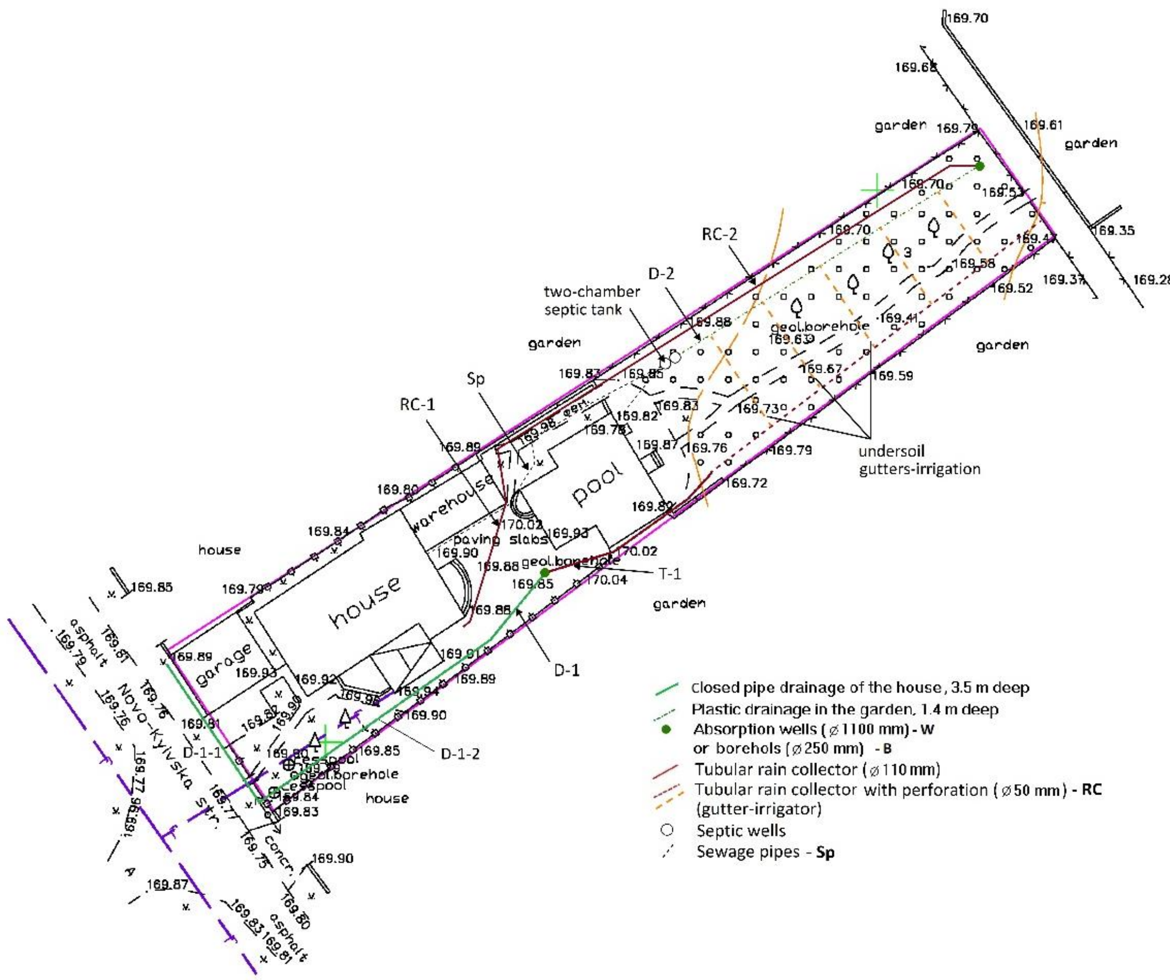

Fig. 5. Plan of the local drainage design site

the site (Figs. 4, 5) is due to the lack of natural and artificial means of accelerated water drainage near the site of works (including beams, ravines, roadside ditches, centralized storm sewers). In compressed building conditions, it is advisable to use polymer sand wells, which are assembled from individual rings 0.2 m high, 1100 mm in diameter, and weighing 44 kg. An absorbing well is drilled through the bottom of the well; a working column is installed, the bottom 40 cm is perforated, and the bottom is covered with a metal mesh and geotextile or fiberglass. A thread is cut in the upper part of the head, which will allow the well to be tightly covered with a lid in case of pressure feeding from below (from a layer of submoren sand).

Conclusions. Unfortunately, the problem of lack of orderly drainage in built-up areas subject to periodic flooding is systemic. It is obvious that it would be more rational to design centralized water lowering and drainage systems (at least to the level of lateral collectors and main ditches) simultaneously with the general development plan of villages and small cities. After dense construction, it becomes almost impossible to lay optimal drainage routes. The algorithm proposed by us for substantiating measures to combat inundation and flooding under the following conditions includes: a) zoning of the territory of the settlement according to the nature of the distribution of precipitation and storm runoff based on radar imaging of rain by a meteorological radar with a high level of temporal (1–5 min) and spatial resolution ability (500 × 500 m); b) calculations of the capacity of the storm network based on radar observations and forecasts of seasonal rainfall, taking into account artificial surface covering; c) detailed study of engineering and geological conditions; d) diagnosis of the causes of flooding and water retention in individual areas, highlighting meteorological, geomorphological, hydrogeological, geological and anthropogenic factors; e) storm water drainage calculations based on actual and forecast data; f) selection of technological scheme and calculations of closed drainage.

The design and construction of the drainage system, even in small areas, should be preceded by detailed engineering and geological investigations to a depth of 6–8 m. In the presence of several interconnected aquifers (horizons), the nature of their interaction should be clarified (the presence of pressure feeding of the upper horizon).

The capacity of the collector for the removal of atmospheric precipitation must be substantiated on the basis of climatic forecasts. However, the current changes in the amount of extreme precipitation, in particular the maximum daily precipitation in April 2023, exceed the predicted values by more than 40 % (compared to the period 2001–2010). When calculating the drainage capacity, it should be taken into account that the maximum amount of precipitation in the future period will have a guarantee of 0.5–2.0 % less than the actual maximum values.

In the conditions of dense construction, if it is impossible to arrange a contour drainage, a single-line horizontal drainage at a depth of 3/5 m can be effective enough to reduce high LGW. Calculations of the zone of influence of the drainage can be performed according to the equations for the inter-drain distances in conditions of unstable and steady inflow regimes. It was established that the influence of the drain in fluvioglacial sand-clay deposits extends in one direction for a distance of about 60 m in an unstable regime, and about 80 m in a stable regime. The technological drainage solution, in our case, included an absorbing well, which was determined by the peculiarities of local conditions: the wedging of the main water-permeable collector in the upper part of the cut and the absence of an open water receiver.

Future research should focus on the collection of high-resolution rainfall and local urban runoff data, as well as the implementation of urban drainage models and the development of compact and efficient drainage facilities.

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ПРИНЦИПИ РОЗРАХУНКІВ ТА ОБЛАШТУВАННЯ ЛОКАЛЬНИХ СИСТЕМ ДРЕНАЖУ НА ТЕРИТОРІЯХ ПРИВАТНОЇ ЗАБУДОВИ

О.Л. Шевченко[1], докт. геол. наук, А.О. Стрельцов[2], аспірант

[1] Український гідрометеорологічний інститут ДСНС України та НАН України;
https://orcid.org/0000-0002-5791-5354; e-mail; shevch62@gmail.com;
[2] Інститут геологічних наук НАН України;
https://orcid.org/0009-0008-5394-8731; e-mail; streltsov.kiev.ua@gmail.com

Анотація. *Аномально рясні дощі за два перші весняні місяці 2023 р. виявили непідготовленість та незахищеність багатьох населених пунктів Київщини від надмірної кількості вологи та затоп-*

лення. Серед таких і с. Нові Петрівці, де несприятливі природні умови для поверхневого стоку та інфільтрації опадів (відсутність видимих ухилів поверхні та слабопроникні покривні відклади), істотно ускладнені забудовою та сіткою автошляхів. Тривала затримка води на поверхні, підйом рівнів ґрунтових вод та шарувата будова верхньої частини геологічного розрізу дають підстави для застосування комбінованих локальних систем дренажу з дотриманням норм осушення не менше 3,0 м. Оскільки висока щільність забудови часто не дозволяє облаштовувати контурний дренаж навколо житлових будинків, доводиться закладати однолінійний горизонтальний дренаж на більшу, ніж для звичайного контурного дренажу глибину – 3,5 і більше метрів. Проте, відсутність придорожніх канав та інших водоприймачів та засобів впорядкованого водовідведення не дозволяють працювати присадибним системам дренажу максимально ефективно. Це потребує створення впорядкованої системи водоприймачів (траншей і закритих колекторів) в масштабах селища. Закордонний досвід переконує, що раціональне планування таких систем можливе за умов встановлення характеру розподілу дощових опадів із роздільною здатністю 1–5 хвилин за часом і кроком в 500 м по площі. Для запису радіолокаційних зображень дощу та вивчення його інтенсивності використовується метеорологічний радар. Ефективне вирішення проблеми водовідведення неможливе без детальних інженерно-геологічних вишукувань. Завдяки ним на локальній ділянці було виявлено літолого-фаціальні неоднорідності в зоні аерації та водонасиченій товщі, які зумовлюють затримання і підпір ґрунтових вод. Врахування просторових меж цих інженерно-геологічних елементів дозволяє розташувати дренаж більш ефективно. Пропускну здатність дренажу обґрунтовано прогнозами змін максимальної кількості опадів за добу і дві доби поспіль. При розрахунках пропускної здатності дренажу слід враховувати, що максимальна кількість опадів майбутнього періоду матиме забезпеченість на 0,5–2,0 % меншу, ніж фактичні максимальні значення. В розрахунковій частині головна увага приділена підбору рівнянь для визначення ширини впливу одиночної горизонтальної дрени. Підібрано п'ять формул, які можуть бути застосовані для вирішення подібних завдань. Вирахувано час настання усталеного режиму роботи одиночної дрени. Майбутні дослідження мають бути зосереджені на зборі даних про опади високої роздільної здатності та місцевий міський стік, а також на реалізації моделей міського дренажу.

Ключові слова: *дренаж, рівень ґрунтових вод, підтоплення, приватна забудова, затоплення, опади, забезпеченість, водовідведення, кліматичні зміни*

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EVALUATION OF POSSIBILITIES FOR USING ELECTROCHEMICALLY ACTIVATED WATER FOR IRRIGATION

M.I. Romashchenko[1], Doctor of Technical Sciences, B.I. Konakov[2], Ph.D. in Technical Sciences, O.A. Nikytiuk[3], Doctor of Agricultural Sciences, A.V. Yarosh[4], Ph.D. in Agricultural Sciences

[1] Kyiv Agrarian University of the National Academy of Agrarian Sciences of Ukraine, Kyiv, Ukraine;
https://orcid.org/0000-0002-9997-1346; e-mail: mi.romashchenko@gmail.com;
[2] Kyiv Agrarian University of the National Academy of Agrarian Sciences of Ukraine, Kyiv, Ukraine;
https://orcid.org/0000-0003-3065-4745; e-mail: crony@meta.ua;
[3] Kyiv Agrarian University of the National Academy of Agrarian Sciences of Ukraine, Kyiv, Ukraine;
https://orcid.org/0000-0002-5679-4247; e-mail: oleksandr.nikytiuk@gmail.com;
[4] National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine;
https://orcid.org/0000-0002-1680-0091; e-mail: yaroshanna@ukr.net

Abstract. *In order to check the possibility of using electrochemically activated water (ECHAW) in irrigation, a study was conducted to determine the influence of anolyte on biological pollutants of wastewater and the reduction of water mineralization by electrochemical activation, as well as the influence of catholyte and anolyte on the germination of seeds of cereal crops, the development of seedlings of pepper and tomato, and the yield of tomato. The research was conducted in laboratory conditions on two varieties of pepper and four varieties of tomato. ECHAW was obtained using laboratory water activators of our own production. Wastewater samples were taken at the Bortnychy wastewater aeration station in Kyiv. Experiments were carried out using vegetation containers of various types and one-time bacteriological tests. It was found that by electrochemical activation of mineralized water it is possible to reduce the level of its total mineralization by more than 50 % and, with an anolyte, to destroy disease-causing bacteria in wastewater. The use of ECHAW accelerates the germination of seeds of cereal crops. On the 3rd day of germination, wheat grain germinated using EHCAW has a 9 % longer root length than the grain germinated under the same conditions using non-activated water. Wheat grain germinated using EHCAW also has 33 % longer sprouts. The growth rate when irrigated with activated water, depending on the variety of tomato plants, increases by 9.8…25.2 %, the increase in stem diameters was equal to 11.3…22.4 %. The yield of tomatoes when irrigated with activated water is 12.6…15.8 % higher than in the case of irrigation by ordinary water, the size of the fruits is 15.4…25.1 % larger. The results of the conducted research indicate the possibility and perspective of using EHCAW to increase the yield of crops under irrigation and improving the quality of drainage and wastewater by reducing their mineralization and providing their disinfection.*

Key words: *electrochemical activation of water (ECHAW), anolyte, catholyte, reduction of drainage water mineralization, wastewater disinfection, irrigation with activated water*

Relevance of research. The water shortage in Ukraine, which exists on the background of intense global warming, is intensificated as a result of the military aggression of the Russian Federation, in particular, the destruction of the Kakhovsky reservoir and other facilities intended for the storage, distribution, and supply of water to settlements, industrial and agricultural structures. In this situation, saving water when using it for various purposes, as well as the efficiency of this use, is of high importance. One of the promising means of increasing the efficiency of water use in irrigation, according to the results of the analysis of information sources, is the use of electrochemical activation of water to increase the yield of crops, to reduce the mineralization of drainage water, and to disinfect wastewater with the aim of using it for irrigation.

Analysis of recent research and publications. Studies devoted to the possibilities of using electrochemical activation and anolytes to reduce mineralization and to disinfect irrigation water have recently been conducted by K. Ghebremichael, E. Muchelemba, B. Petrusevski [1], Geletu Qing, Zahra Anari, Shelby L. Foster, Marty Matlock, Greg Thoma, Lauren F. Greenlee, Mojtaba Abolhassani, Raheleh Daneshpour [2, 3], John W. Bartok jr. [4] and other researchers. The Royal Brinkman company proposes the use of electrochemically activated water as an environmentally sound alternative to modern chemicals for disinfecting irrigation water in horticulture [5]. The prospects of electrochemical activation to reduce mineralization and anolytes for disinfection as an alternative to traditional disinfectants in agriculture were investigated by Ukrainian scientists H.S. Stolyarenko, R.O. Azizov, B.I. Tupytskyi, A.V. Lysitsa, Yu.M. Mandigra [6, 7] et al.

The works of Abdullaev M.T., Zakirov K.R., Khaitov B.A. and some other authors are devoted to the use of electrochemically activated water in the pre-sowing treatment of vegetable seeds [8]. Regulation of acidity in conditions of covered soil and improvement of vegetable crops with the help of electrochemically activated water was studied by D.S. Tsokura, S. Ya. Semenenko, M. N. Belitskaya, S. M. Lykholetova [9, 10] et al. O. I. Chushkin, S. Ya. Semenenko, M. N. Lytov, A. N. Chushkin, O.V. Amcheslavskyi [11–17] et al. investigated the issue of using ECHAW to increase the productivity of tomato and other vegetables under drip irrigation, which is considered the most promising method of irrigation for the use of electrochemically activated water.

The purpose of the research is to determine the possibilities of improving drainage and wastewater with components of electrochemically activated water for irrigation purposes, as well as to determine the effect of irrigation with such water on the germination of seeds of cereal crops, the development of seedlings and the yield of vegetable crops.

Research materials and methods. The devices for electrochemical activation of water, determination of its acidity and oxidation-reduction potential, air temperature, nutrient content and soil moisture, measuring instruments, scales, etc. were used. The following theoretical and practical methods of scientific research are applied: analytical method, modeling, laboratory-vegetation method.

Research results and their discussion. *Research on the possibilities of reducing the mineralization of drainage waters by means of their electrochemical activation and disinfection of wastewater with an anolyte.* In connection with the metastable properties of the components of the electrochemical activation of water and the need to have freshly prepared volumes of anolyte during the experiments, according to the well-known scheme of Krotov D.I. [10], a laboratory device was developed and manufactured. It allows us to obtain catholytes with pH values up to 10 and ORP up to −500 mV and anolytes with pH values up to 4 and ORP up to +600mV (Fig. 1a). The anolyte container is made of cotton ultrafiltration material Belting "BF" 2030 C-1 with the density equal to 1000 g/m^2 (Fig. 1b), the electrodes are made of VT1-00 titanium (Fig. 1c).

To determine the possibility of reducing the total mineralization of drainage waters by means of their electrochemical activation, laboratory studies using model solutions were conducted. Considering that Na and Cl ions significantly determine the level of general mineralization of drainage water and are the most difficult components in terms of removal during electrolysis, model solutions were prepared by adding table salt to tap water. Water solutions of table salt were prepared in volumes of 1 dm^3 with levels of total mineralization from 2100 ppm to 6900 ppm. These solutions were electrochemically activated in a 1 *l* container for 4 to 14 minutes. The activation time was limited by raising the temperature to 55…60 °C. The following devices were used during the

a b c

Fig. 1. Device for obtaining catholyte and anolyte in laboratory conditions: a – general view; b – cotton container for anolyte (ultrafiltration membrane); c – electrical unit

experiments: pH meter, TDS meter, ORP meter, thermometer, DT-830 multimeter.

Table 1 shows the changes in the general mineralization of water solutions under the influence of electrochemical activation.

The data given in Table 1 show that the electrochemical activation of mineralized water solutions allows after 4…14 min to reduce their total mineralization by 48,3…66,7 %. When conducting these experiments, the activation time and the activation electric current were also recorded. In view of this, it was determined that the energy intensity of the electrochemical activation of water by the laboratory activator was 30.5…39.7 kWh/m^3. The energy intensity of industrial facilities, as evidenced by literature, is almost an order of magnitude lower. The conducted studies confirm the possibility of reducing the mineralization of mineralized, in particular, drainage water by means of their electrochemical activation.

To assess the antimicrobial effect of anolyte, experiments were conducted on its ability to destroy widespread and dangerous microorganisms – E. Coli coliform bacteria, which are quite resistant to many standard disinfectants. The WaterWorks ™ Bacteria Check tests of the Industrial Test Systems Inc (USA) company were used for the experiments, which meet the requirements of the EPA – the US Agency for the Protection of the Environment and Human Health (Fig. 2a, 2b). The effect of anolyte on improving the biochemical composition of wastewater was studied by adding anolyte water to selected wastewater samples and further observing the result of the destruction of pathogenic microorganisms present in the water.

Wastewater samples were taken at the Bortnychy wastewater aeration station in Kyiv (Fig. 2c). The collection was carried out in accordance with the requirements of the “Instructions for the collection and preparation of water and soil samples for chemical and hydrobiological analysis by hydrometeorological stations and posts”, approved by the order of the Emergency Department of Ukraine dated 19.01.2016 No. 30.

First, the presence of bacteria in each of the selected samples was tested (Fig. 3a, 3b). To do this, according to the instructions for using the tests, 100 ml of water from each sample was collected in 2 jars with bacteria and thoroughly mixed with the contents of the jars. After that, the mixture was left in the room for 48 hours. The results of this test demonstrated the presence of E. Coli bacteria in both water samples (Fig. 3c).

The volume of anolyte required for the destruction of biological pollutants in wastewater samples was calculated taking into account the existing information on this matter. The volume of 90 ml of waste water of each sample was collected in two jars and 10 ml of anolyte with values of ORP = +600 and pH 4 was added and thoroughly mixed with the contents of the jars. In

1. The change in the level of general mineralization of water solutions under the influence of electrochemical activation

Primary total mineralization, g/dm^3	2.1	3.2	3.9	4.8	6.0	6.9
Activation time, min	14	12	10	8	6	4
Total mineralization after activation, g/dm^3	0.7	1.1	1.6	2.3	3.1	3.5
Reduction of total mineralization after activation, %	66.7	65.7	59.0	52.1	48.3	49.3

a b c

Fig. 2. WaterWorks ™ Bacteria Check tests on E. Coli bacteria and a sample of wastewater from the Bortnychy aeration station: a – the jar with the Bacteria Check test; b – the samples of tested subjects (on the left – yellow color – bacteria are present, on the right – purple color – bacteria are absent); c – the wastewater sample

a b c d

Fig. 3. Testing the presence of E. Coli bacteria in wastewater samples: a – the laboratory electrochemical water activator; b – WaterWorks ™ Bacteria Check tests; c – the test of wastewater samples without anolyte disinfection (positive – living bacteria are present); d – the test of wastewater samples after disinfection with anolyte (negative – no living bacteria present)

the same way, 95 ml of water from each sample was collected in two more jars, 5 ml of anolyte with values of ORP = +600 and pH 4 was added, thoroughly mixed, and left for 48 hours. The results of all tests proved the absence of living bacteria in the wastewater (Fig. 3d).

The conducted experiments demonstrate the possibility of using anolytes for wastewater disinfection during its preparation for irrigation.

Research on the influence of electrochemically activated water on the germination of cereal crops seeds. The influence of electrochemically activated water on the germination of cereal crop seeds was determined by conducting comparative experiments (when irrigated with activated and non-activated water) on the germination of wheat and corn seeds. Germination was carried out using germinating jars (Fig. 4a) and an automatic grain and seed germinator (Fig. 4b), which provides optimal temperature and humidity. Wheat of the "Diana" variety and corn of the "DB Khotyn" variety were used for the experiments. For germination, 100 g of corn and wheat grains were placed in germinating jars soaked in activated water (anolyte pH 4,6…5,1; ORP 480…550mV; catholyte pH 8,5…9,3; ORP: – 260… – 480 mV) and ordinary water. The seed were also placed in the automatic germinator.

Studies on the germination of wheat and corn seeds were carried out for 3 days. Fig. 5 shows the appearance of wheat and corn seeds at the end of the 3rd day of germination.

On the third day, 20 seeds with the largest roots and sprouts were selected from the germinated wheat and corn grains of each variant, their sizes were measured and the average values were determined. All variants were weighed. The results of the morphological indicators of the germination of wheat and corn seeds when soaked with ECHAW and ordinary water are given in table. 2.

From the analysis of the data given in Table 2 it can be seen that the wheat seeds germinated using ECHAW on the third day have a 9 % longer root length than in the case when non-activated water was used. They also have 33 % longer sprouts. For corn, it is 20 % and 3 %, respectively.

a b

Fig. 4. Germination of wheat and corn seeds: a – the germinating jars; b – the automatic germinator of grain and seeds

a b c

Fig. 5. Sprouts of wheat and corn seeds on the third day of germination: a and b – in the jars for germination; c – in the automatic seed germinator

2. Morphological indicators of germinated wheat and corn seeds when soaked in ECHAW and ordinary water

Seeds type	Activated water		Non-activated water	
	roots, mm	sprouts, mm	roots, mm	sprouts, mm
wheat	33	24	30	18
corn	18	36	15	35

3. Weighted indicators on the 1st and 3rd day of germination of wheat and corn seeds when soaked with ECHAW and ordinary water

Seeds type	Seeds weight, g					
	Activated water			Non-activated water		
	germination day		%	germination day		%
	1st mass, g	3rd		1st	3rd	
wheat	100	201	101	100	191	91
corn	100	154	54	100	152	52

Table 3 shows weighted indicators on the 3rd day of germination of wheat and corn seeds when soaked in ECHAW and ordinary water.

According to the analysis of the data from Table 3 it can be seen that the use of activated water during the germination of corn and wheat seeds at the temperature of 18…21 °C and water changes three times per day ensures an increase in the mass of germinated wheat by 10 %, and corn by 2 %.

Research on the influence of electrochemically activated water on the development of seedlings and the yield of vegetables. The influence of irrigation with ECHAW on the development of vegetables seeds was studied by conducting laboratory vegetation experiments during irrigation with activated and non-activated (control) water in vegetation containers made of polyethylene bottles (Fig. 6a, 6b). Establishing the influence of irrigation with ECHAW on the development and yield of vegetables in covered soil conditions was carried out using “Grow Bag” vegetation containers made of moisture-resistant “breathable” eco-fabric (Fig. 6c). Agrotechnical characteristics of the soil was as follows: pH level – 6.0…6.5; total nitrogen – 80…120 mg/l; phosphorus – 100…150 g/l; potassium – 140…180 g/l; trace elements – B, Cu, Fe, Mn, Mg, Mo, Zn.

Experiments on growing seedlings of vegetables were conducted on two varieties of peppers (“Gourme” and “Lecho”) and two varieties of tomatoes (“Orange” and “Cardinal”). Seeds were sown directly into the soil in vegetation containers. Soil moisture during sowing was 70…89 % of field capacity (which is the optimal moisture level for tomato and pepper), air temperature – 18…20 °C, air humidity – 50…60 %. Parameters of electrochemically activated water were as follows: ORP of anolyte = + 500….+550 mV, pH – ~5; OVP of the catholyte – 260…–480 mV at pH 8.5…9.3.

Evaluation the effect of ECHAW on the development of tomatoes from sowing to harvesting was carried out for two varieties of dwarf tomatoes: indoor “Bonsai” and balcony “Cherry gold”.

a b c

Fig. 6. Vegetation containers for conducting research in laboratory conditions:
a, b – made of 2 and 5 *l* polyethylene bottles for germination and seedling growth;
c – 20-liter containers "Grow Bag"

Peppers were sown on March 4, 2023. 80 seeds of the "Lecho" variety and 80 seeds of the "Gourme" variety were selected for sowing. The seeds of each variety were sown into a depth of 7 mm in four 2-liter PET bottles with soil. The soil was irrigated with the mixture of catholyte with the following parameters: pH – 8.5…9.3; ORP: −260…−480 mV and anolyte with pH 4.6…5.1; ORP 500…550 mV. The watering, in accordance with existing information on this matter, were carried out with a ratio of anolyte to catholyte equal to 1:4 in one irrigation with separation of non-activated water in a ratio of 1:1 with non-activated water. The total mineralization of non-activated water (from the city water network) during the experiments was from 120 to 180 ppm. After each watering with activated water, 3 irrigations with ordinary water were carried out. Soil moisture was monitored using a conductometric soil moisture sensor and maintained at the level of 75…90 % of field capacity. Germination of pepper plants appeared from March 18 to March 23, 2023.

Table 4 contained the data on seeds germination and average plant height of pepper seedlings as of April 27, 2023. As it can be seen from Table 4, watering pepper seeds with electrochemically activated water increased the percentage of germination of the "Gourme" variety by 3,3 %.

On the 37th day of development, watering with activated water ensured an increase in the height of "Lecho" and "Gurme" pepper plants by 13.2…18.1 % compared to plants irrigated with non-activated water, and on the 46th day of development – by 14…19.2 %. Tomatoes of the "Orange" and "Cardinal" varieties were sown on March 30, 2023, and sprouted from April 5, 2023 to April 09, 2023. Table 5 contained the data on seeds germination and average plant height of tomato seedlings as of April 27, 2023.

During the experiments on the development of tomato seedlings, the increase in the diameters

4. Germination of seeds and average height of pepper plants as of 27.04.2023.

Variety	**Germination of seeds**		**Increase in growing, %**	**The average height of plants, cm**		**Increase in growing, %**
	Activated water	**Ordinary water**		**Activated water**	**Ordinary water**	
Lecho	28	28	0	5.3	4.6	13.2
Gourme	30	29	3.3	5.5	4.5	18.1

5. Germination of seeds and average height of tomato plants as of 27.04.2023.

Variety	**Germination of the seeds**		**Increase in growing, %**	**The average height of plants, cm**		**Increase in growing, %**
	Activated water	**Ordinary water**		**Activated water**	**Ordinary water**	
Orange	30	30	0	6.5	4.8	20.1
Cardinal	39	34	18.8	7.3	5.5	24.6

of plant stems at the height of 10 mm above the soil was also analyzed. The average stem diameter of tomato plants of the "Orange" variety at the height of 10 mm above the soil on the 45th–50th day of development under irrigation with activated water was 22.4 % larger than the average diameter of plants irrigated with ordinary water. For the "Cardinal" variety this percentage was equal to 11,3 %.

Evaluation of the influence of electrochemically activated water on the development of vegetables from sowing to harvesting was carried out on two varieties of dwarf tomatoes: indoor "Bonsai" and balcony "Cherry gold". These tomatoes were sown in two-liter seedling containers on May 14, 2023. 12 seeds of each variety were sown, half of which were irrigated with activated water and another half – with ordinary water according to the above-described scheme. The seeds of these tomatoes germinated on May 19…20, 2023. After growing the seedlings, 8 plants of each variety were planted in the "Grow Bag" containers (Fig. 6b) for the continuation of laboratory vegetation experiments, 4 of which were irrigated with activated water and 4 with non-activated water (16 plants in total).

"Bonsai" tomatoes entered the flowering phase on July 03, 2023, "Cherry Gold" – on July 12, 2023. "Bonsai" tomatoes began to bear fruit on August 14, 2023, and "Cherry Gold" – on August 23, 2023 (Fig. 7).

Table 6 contains data on the collection period and the yield obtained from 8 tomatoes bushes of the "Bonsai" variety and from 8 bushes of the "Cherry Gold" variety.

Analysis of the data in Table 6 shows that the use of electrochemically activated water for irrigating balcony tomatoes of the "Bonsai" variety led to an increase in their yield by 15,8 %. When irrigating "Cherry Gold" tomatoes an increase was equal to 12,6 %. Weighing and comparing the geometric dimensions of "Bonsai" and "Cherry Gold" tomatoes showed that watering with activated water leads to an increase in the size of the fruits of the "Bonsai" variety by 15.4…25.1 % and an increase in weight by 15.3 … 38.5 %. For the "Cherry Gold" variety, this increase was, respectively, 16.2…17.4 % and 17.9…28.2 %.

Taking into account that this paper is prepared on the basis of the results of exploratory scientific research, statistical substantiation, with high reliability of the given data, can be obtained only after the implementation of full-fledged projects in this scientific field.

Conclusions. The performed studies confirmed the possibility of reducing the mineralization of drainage waters by means of their electrotechnical activation and of disinfection of

a b c

Fig. 7. Appearance of tomato fruits and plants in the fruiting phase: a and b – "Bonsai"; c – "Cherry Gold"

6. Dates and yield of "Bonsai" and "Cherry Gold" tomatoes

"Bonsai"									
Water	dates	15.08	19.08	23.08	28.08	5.09	11.09	Total	Increase, %
Activated	yield, g	532	890	1760	733	583	207	4705	15,8
Non-activated		308	739	1643	652	430	188	3960	

"Cherry Gold"								
Water	dates	23.08	28.08	3.09	10.09	17.09	Total	Increase, %
Activated	yield, g	315	634	512	436	186	2083	12,6
Non-activated		377	529	472	306	136	1820	

wastewater with anolyte during their preparation for irrigation. Final recommendations on the use of electrochemically activated water and its components for these purposes can be formulated after full-fledged research on this topic. It was established that the use of electrochemically activated water improves the germination of cereals and has a positive effect on the growth of sprouts and roots of the germinating seeds. Wheat seeds germinated using electrochemically activated water on the 3rd day of germination has a 9 % longer root length than grain germinated under the same conditions using non-activated water. The sprout length in this case was 33 % longer. Irrigation of pepper and tomato with electrochemically activated water confirmed its influence on accelerating the development of these crops. The germination of tomatoes when watering with activated water increased by 18.8 %, the growth of the height of pepper plants – up to 19.2 %, tomatoes – up to 25.2 %. The yield of tomatoes irrigated with activated water increased by 15.8 %, the size of the fruits – by 25.1 % (with an increase in weight by 38.5 %). Detailed recommendations for the use of electrochemically activated water in the cultivation of vegetable crops can be developed after conducting full-fledged research. Taking into account the peculiarities of the components of electrochemically activated water – a short relaxation time of the catholyte and a rather long relaxation time of the anolyte, as well as the scope of their application in irrigation abroad – the use of electrochemically activated water in drip irrigation systems can be considered the most promising.

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ОЦІНЮВАННЯ МОЖЛИВОСТЕЙ ЗАСТОСУВАННЯ ЕЛЕКТРОХІМІЧНО АКТИВОВАНОЇ ВОДИ ДЛЯ ЦІЛЕЙ ЗРОШЕННЯ

М.І. Ромащенко[1], докт. техн. наук, Б.І. Конаков[2], канд. тех. наук, О.А. Никитюк[3], докт. с.-г. наук, А.В. Ярош[1], канд. с.- г. наук

[1] Київський аграрний університет НААН, Київ, Україна;
https://orcid.org/0000-0002-9997-1346; e-mail: mi.romashchenko@gmail.com;
[2] Київський аграрний університет НААН, Київ, Україна;
https://orcid.org/0000-0003-3065-4745; e-mail: crony@meta.ua;
[3] Київський аграрний університет НААН, Київ, Україна;
https://orcid.org/0000-0002-5679-4247; e-mail: oleksandr.nikytiuk@gmail.com;
[4] Національний університет біоресурсів і природокористування України, Київ, Україна;
https://orcid.org/0000-0002-1680-0091; e-mail: yaroshanna@ukr.net

Анотація. *З метою перевірки можливостей застосування електрохімічно активованої води (ЕХАВ) для цілей зрошення проведено дослідження з визначення впливу аноліту на біологічні забруднювачі стічних вод і зменшення електрохімічною активацією рівня мінералізації вод, а також впливу католіту і аноліту на проростання насіння зернових культур, розвиток розсади перців і томатів та врожайність томатів. Дослідження проводили в лабораторних умовах на двох сортах перцю і чотирьох сортах томату. Отримання ЕХАВ здійснювалось із використанням лабораторних активаторів води власного виготовлення. Проби стічної води відбирали на Бортницькій станції аерації стічних вод міста Києва. Досліди проводили з використанням вегетаційних контейнерів різних видів та одноразових бактеріологічних тестів. Встановлено, що електрохімічною активацією мінералізованих вод можна досягати зниження рівня їх загальної мінералізації більш, ніж на 50 %, а анолітом знищувати хвороботворюючі бактерії в стічних водах. Застосування ЕХАВ прискорює проростання насіння зернових культур. Зерно пшениці, пророщене за використання ЕХАВ, на 3-й день пророщування має довжину коренів на 9 % довшу, ніж зерно, що пророщене в таких самих умовах за використання неактивованої води, а довжину паростків – на 33 %. Швидкість росту при зрошенні активованою водою, залежно від сорту рослин томатів, підвищується на 9,8–25,2 %, збільшення діаметрів стебел – на 11,3–22,4 %. Врожайність томатів при зрошенні активованою водою на 12,6–15,8 % вища, ніж при зрошенні звичайною водою, крупність плодів більша на 15,4–25,1 %. Результати проведених досліджень свідчать про можливість і перспективність застосування ЕХАВ для підвищення врожайності с.-г. культур в зрошенні та поліпшення якості дренажних і стічних вод шляхом зниження їх мінералізації та знезараження.*

Ключові слова: *електрохімічна активація води (ЕХАВ), аноліт, католіт, зниження мінералізації дренажних вод, обеззараження стічних вод, зрошення активованою водою*

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MONITORING OF WATER BODIES AND RECLAIMED LANDS AFFECTED BY WARFARE USING SATELLITE DATA

O.V. Vlasova[1], Doctor of Agricultural Sciences, A.M. Shevchenko[2], Ph.D. in Agricultural Sciences, I.A. Shevchenko[3], Ph.D. in Technical Sciences, O.M. Kozytsky[4]

[1] Institute of Water Problems and Land Reclamation of National Academy of Agrarian Sciences of Ukraine, Kyiv, Ukraine; https://orcid.org/0000-0002-1911-4329; e-mail: elena_vl2001@ukr.net;
[2] Institute of Water Problems and Land Reclamation of National Academy of Agrarian Sciences of Ukraine, Kyiv, Ukraine; https://orcid.org/0000-0002-2637-6538; e-mail: monitoring_protect@ukr.net;
[3] Institute of Water Problems and Land Reclamation of National Academy of Agrarian Sciences of Ukraine, Kyiv, Ukraine; https://orcid.org/0000-0002-7401-8786; e-mail: irashef@ukr.net;
[4] Institute of Water Problems and Land Reclamation of National Academy of Agrarian Sciences of Ukraine, Kyiv, Ukraine; https://orcid.org/0000-0002-4459-6331; e-mail: olegkoz@ukr.net

Abstract. *The paper presents the results of monitoring the state of water bodies and reclaimed lands affected by warfare using remote sensing methods and in-situ surveys. On the example of the flooding of the floodplain of the Irpin river by the waters of the Kyiv reservoir as a result of the destruction of the culvert structure, as well as the flooding of the floodplain of the Dnipro river near village Otradokamyanka after the explosion of the Kakhovska hydro power plant (HPP), the change in the area of inundation was calculated based on spectral index maps and surface classification using Sentinel-2 L2A imagery. On the base of Sentinel-2 L2A images, maps of SAVI and NDWI indices were obtained. They revealed the places of soil cover by sediments and the increase of the area of water bodies. Monitoring of reclaimed lands affected by warfare was carried out in the floodplain of the Irpin river on the Irpin Drainage and Moistening System during three time intervals: before the war in 2019; during the fighting in the spring of 2022 and a year after the end of military actions. Studies have shown a significant prevalence of waterlogged areas in the present time, which confirms the destruction of drainage network.*

The calculated values of the NDVI index turned out to be too high for agricultural crops, which indicates that the lands is overgrown with shrubs. Based on the results of the conducted monitoring, the territory was classified according to the degree of its damage by shell craters. Based on the results of the studies, it is recommended to monitor water bodies and reclaimed lands that have been affected by the war using images of different spatial resolution, a complex of spectral indices, a combination of image bands and in-situ surveys.

Key words: *water bodies, reclaimed lands, military actions, satellite images, spectral indices, level of damages*

Relevance of research. Since the beginning of the war with the Russian Federation, Ukraine has faced significant negative consequences of hostilities, which led not only to direct destructions and economic losses, but also affected the environment, in particular, water bodies and land resources. The problems related to the use and ecological condition of reclaimed lands due to their fouling, pollution, damage or destruction of hydraulic facilities, objects of engineering infrastructure of irrigation and drainage systems, etc., have been significantly aggravated. The destruction of the Kakhovska hydro power plant (HPP) dam and, as the result, emptying of the Kakhovska reservoir caused extra damages and losses to both the population and the economy of the country, as well as the environment. Assessing the effects of military actions and large-scale destruction of hydraulic facilities on the environment using in-situ methods is quite difficult. For its practical solution, the development and elaboration of scientific approaches with the use of remote sensing technologies and the application of independent spatially distributed satellite information is relevant. This especially applies to the levels of river floodplains flooding after the detonation of hydraulic facilities and damages to drainage and irrigation systems on reclaimed lands.

Analysis of recent studies and publications. The most common and unpredictable natural phenomena are floods and man-made disasters that cause great economic losses, harm communities, and affect human lives. Therefore, quick and accurate determination of areas flooded by surface waters is of a great necessity for monitoring the changes that occur within river basins, especially as a result of military actions [1–6]. In this context, multispectral (multiband) satellite images of the Landsat 8 and Sentinel-2 L2A systems can be an accessible and irreplaceable source of information [7–10]. In global practice, based on the difference between spectral reflectance of water, soil, and vegetation covers, spectral indices for water, soil, and vegetation are calculated as the indicators of the natural state of mentioned surfaces [6, 12]. Spectral indices are used to classify a certain type of land cover [13, 14]. The Normalized Difference Water Index (NDWI) is used to identify water bodies on a background of soil and vegetation covers [15, 16], the Normalized Difference Vegetation Index (NDVI) is used for vegetation cover, etc. Recently, the use of various combinations of satellite images' bands has become widespread. For example, we can single out Red8, SWIR1, Red (abbreviated as RSR). This combination of the near, mid-IR bands, and the visible red band makes it possible to clearly distinguish the boundary between water and land, as well as to emphasize hidden poorly visible details when using only a range of visible bands [17–19].

In the literature, the issue of flooded areas identification with the help of multispectral satellite data and spectral indices obtained on their basis is sufficiently covered [20–23]. A lot of attention is paid to the use of SAR images and the determination of catchment area structure, the study of climate changes, soil and climate potential, and the ecological state of river basins [24]. However, practice shows that incorrect or unsuccessful use of calculated spectral indices leads to erroneous results and conclusions. Only the integrated application of indicators such as spectral indices in their certain combination and comparison makes it possible to perform operational monitoring of water bodies and reclaimed lands. In addition, the analysis of the detected changes makes it possible to determine the reasons for the deterioration or improvement of the situation on a certain territory and to plan further actions for its preservation or restoration.

The aim of the research is to determine the optimal set of indicators – spectral indices and combinations of satellite images' bands for monitoring water bodies and reclaimed lands affected by military actions.

Research methods and materials. The essence of technologies for obtaining satellite spatially distributed data is defined by the observation and measurements of energy and polarization characteristics of own and reflected radiation of water, soil-vegetation surfaces, and the atmosphere in various ranges of the spectrum of electromagnetic emission. During the research with the use of satellite data such methods as geospatial analysis, mathematical modeling, systems of experts evaluations, and field surveys were used.

In the course of research, system analysis was applied. The research methodology included the following components:

– search, analysis of available free information and application of required types of satellite data (multispectral, panchromatic with high spatial resolution);

– calculations of spectral indices for vegetation, soil, and water, comparison of bands combinations;

– analysis of the obtained results and changes that occurred with water bodies and reclaimed lands under the influence of military actions.

During the monitoring based on satellite data and field surveys, observations of water bodies, the condition of agricultural lands located on reclaimed territories, their soil and vegetation cover were performed. The research materials were satellite images and in-situ verification information.

Research results and discussion. In the conducted studies, the main attention was paid to the fixation of negative processes and their consequences in the floodplain of the Irpin river, in particular, in the area of the Irpin drainage and moistening system (DMS) within the Bilohorodka territorial community of the Buchanskyi district, Kyiv region, Ukraine, as well as on the territory along the Dnipro and Kozak rivers within Kherson region.

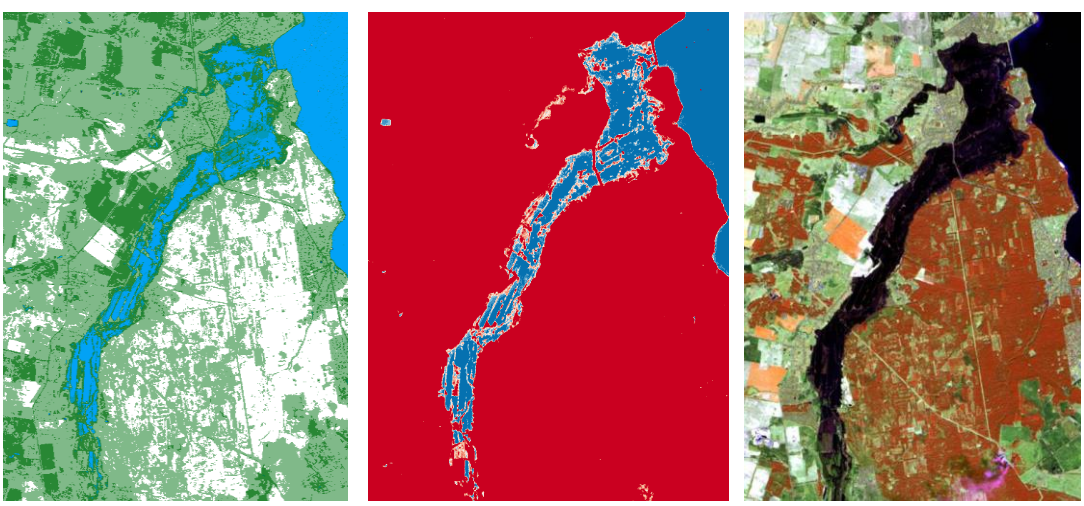
The floodplain of the Irpin river is wide (about 1–2 km), cuted by a dense network of reclamation canals. According to the nature of hydrological regime, the Irpin river and its tributaries belong to the type of rivers mainly fed by snow. Fluctuations in water levels are characterized by a distinct spring flood, low summer-autumn and winter baseflow. Annual short-term rain floods are observed during summer and autumn periods. The peculiarities of river's hydrological regime are caused mainly by the significant regulation of surface runoff, intensive reclamation of the floodplain and the river valley in general, as well as the construction of a polder protective dam at the mouth of the river [25].

During the military actions in the Kyiv region, as a result of the destruction at the end of February 2022 of the culvert structure of the Kozarovytsky protective dam, the floodplain of the Irpin river was flooded by the waters of the Kyiv reservoir in the area of Kozarovychi and Demydiv villages. Later, the flooding reached the outskirts of the villages of Huta Mezhyhirska, Chervone, Moschun, Gorenka, and the settlement Gostomel. We used Sentinel-2 L2A satellite images to assess the impact of the destruction and the scale of the territory flooding. The first image was obtained on March 18, 2022. The flooded area was calculated based on the following indicators: the map of the spectral index – Normalized Difference Water Index (NDWI), which uses reflectance in near-infrared spectrum and visible green light (flooded area was determined on the territory of 17,98 km^2); the map of the Normalized Difference Snow Index (NDSI) (flooded area was determined on the territory of 17/68 km^2); and surface classification with a combination of RSR bands for the separation of land and water bodies (flooded area was determined on the territory of 23/7 km^2) (Fig. 1).

Further, Sentinel-2 L2A images acquired on 07.04.2022, 21.03.2023, 30.05.2023 and Landsat 8 image acquired on 03.06.2022 were used to determine the flooded areas based on the calculated NDWI, NDSI indices, and RSR bands combination. According to the Sentinel-2 L2A image acquired on 07.04.2022 the flooded areas were: NDWI – 17.56 km^2, NDSI – 16.17 km^2, and RSR bands combination – 16.14 km^2. According to the Landsat 8 image acquired on 03.06.2022, the flooded areas were: NDWI – 16.32 km^2, NDSI – snow index was not used during summer period, and RSR bands combination – 19.13 km^2. According to the Sentinel-2 L2A image acquired on March 21, 2023, the flooded areas were: NDWI – 12.74 km^2, NDSI – 11.40 km^2, and RSR bands combinations – 15.03 km^2. According to the Sentinel-2 L2A image acquired on 30.05.2023, the flooded areas were: NDWI – 8.50 km^2, NDSI – snow index was not applied, and RSR bands combination – 14.04 km^2. With the help of this technology, separation of surface water and dry land was carried out, flooded areas were calculated for different dates, and their decrease was recorded. In the course of the study, the Normalized Difference Water Index (NDWI) was used to identify excessively wet areas and the presence of water bodies on the earth surface. For its calculation, reflected near-infrared radiation and visible green range were used.

The Normalized Difference Snow Index (NDSI) is commonly used to establish the spectral differences of snow in the short-wave infrared and visible spectral bands of satellite images. In this case, in the spring, when the ice on the Irpin river began to melt and flooding began, the maps of this index came in handy when calculating the flooded areas taking into account additional water income. The combination of the near, mid-infrared, and visible red RSR bands is taken as the third indicator of flooded areas. This made it possible to clearly distinguish the boundaries between water and dry land, to emphasize imperceptible details when using only bands of the visible range. The usage of a combination of RSR bands was the most effective.

Another water body that was significantly affected by the military actions is the Kakhovsky reservoir. After the explosion of the dam at the Kakhovska HPP on June 6, 2023, significant volumes of water from the Kakhovsky reservoir caused flooding of coastal settlements,



a b c

Fig. 1. Delineation of the flooding zone on March 18, 2022 according to the data from Sentinel-2 L2A: a – NDWI map; b – NDSI map; c – map of the RSR bands combination

agricultural lands, and conservation areas. A fast waterwave washed up the high right bank of the Dnipro river in the first days after the flooding began, which may continue in the future.

The scale of flooding on the studied area along the Dnipro and Kozak rivers near the village Otradokamyanka (Shylova Balka – an object located on the territory of the Kakhovka district, Kherson region, 2,5 km up north from the village Vesele was established using Sentinel-2 L2A satellite images. Maps of the calculated SAVI and NDWI indices are presented (Fig. 2) in the form of a comparison of the situation before the flood (as on 05.06.2023) and after the flood (as on 18.06.2023).

As a result of the monitoring, the places of soil cover damages by sediments and the increase in the area of water bodies were found. On the maps of the soil index the territories with SAVI = 0–0.1 for different dates had the area from 2.49 km^2 to 5,5 km^2 (dark brown color), with SAVI = 0.1–0.2 – from 4.32 km^2 to 8.74 km^2 (light brown color). The greatest damages have been found on the territory of 7.43 km^2. According to the water index maps, the areas increased with the value: for NDWI = 0–0,1 total area was in the range from 0.40 km^2 to 6.16 km^2 (green color of water), for NDWI = −0,3–0 – from 2.98 km^2 to 7.95 km^2 (dark green color of water). The greatest damages have been found on the territory of 10.73 km^2. It should be noted that over time along the coast line, wind erosion can cause migration of heavy metals with the dust.

Monitoring of reclaimed lands affected by military actions was carried out in the basin of the Irpin river. The research was conducted at the Irpinska DMS within the Bilohorodka territorial community during three time intervals: before the war – the growing season of 2019 (according to Landsat 8 satellite data), in the spring of 2022, when military actions were actively taking place, and in the summer of 2023 (according to data from the Sentinel-2 L2A satellite). On the base of the image dated 2019, a working area with coordinates was distinguished and classes of the surface were established, which was confirmed by field surveys. The researched plot with a total area of 466 ha includes fields of agricultural crops (cereals, oilseeds, fodder, root crops), hayfields, pastures, gardens, locally built-up areas, and peats burn by the fires, as well as the lands that are not currently in use. All the lands are characterized by different requirements for water regime and moisture supply conditions. Based on the 2019 Landsat 8 image three spectral indices were calculated and the maps were obtained for the NDVI index, which acts as an indicator of the state of vegetation cover, the ir/r ratio, which made it possible to single out overmoistened areas, and the iron oxide index (IO), which is used to estimate soil fertility (Fig. 3).

As of 2019, the NDVI vegetation index had high values from 0.21 to 0.51, which indicates a developed vegetation and a satisfactory condition of agricultural crops. However, high values of the ir/r ratio in the range of 3.5–4.0 indicate that the existing drainage system does not cope with the removal of excess moisture along the Irpin river

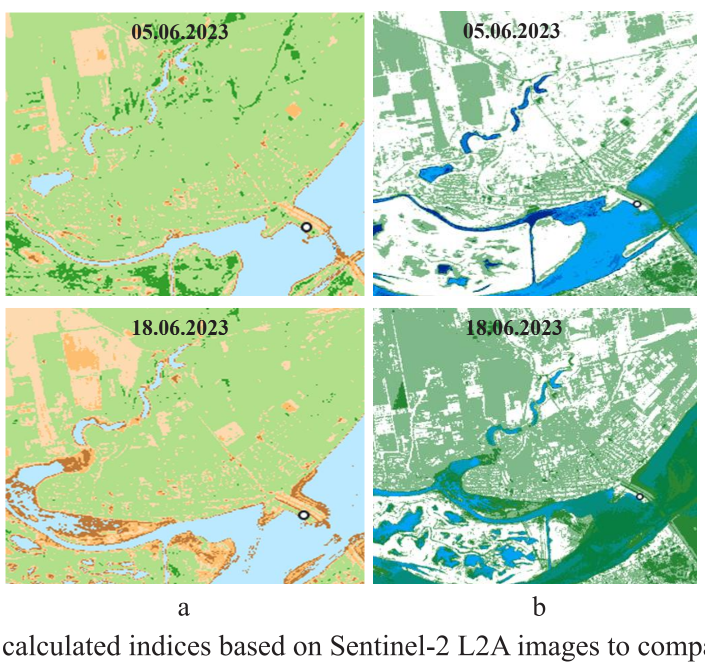


Fig. 2. Maps of calculated indices based on Sentinel-2 L2A images to compare the situation on different dates: a – soil index SAVI, b – water index NDWI.

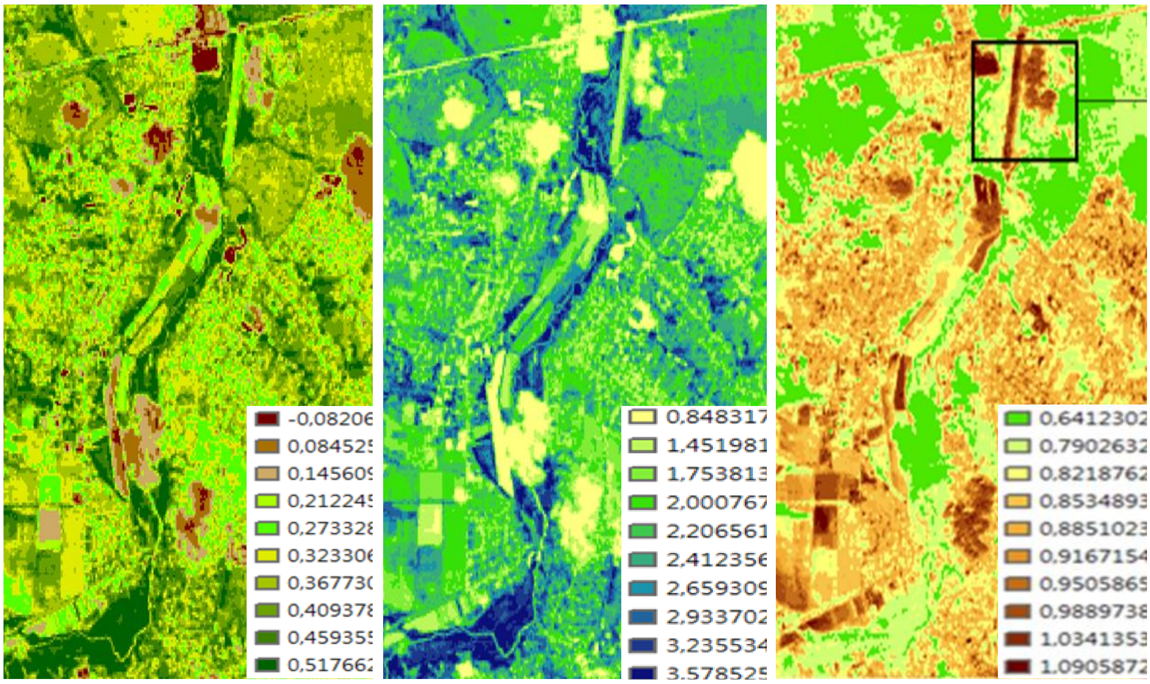


Fig. 3. Maps of calculated spectral indicators based on the Landsat 8 image in 2019:
a – vegetation index NDVI; b – ir/r ratio; c – index of iron oxide IO

and does not ensure a good (quality indicator) conditions of the territory in general. The values of the IO index on the plot are 1.03–1.09, which indicates a sufficient supply of soil with nutrients. In general, the situation was satisfactory.

Over the time, namely in April 2022, shell craters were recorded on the Airbus image. A Sentinel-2 L2A image from June was used to compare the situation one year later and to find out what damage the warfare has done to the territory. According to the combination of RSR bands, wetted and dry areas were estimated, as well as a map of the vegetation index NDVI was obtained, which proves the restoration of the experimental plot (Fig. 4 d). On the RSR map the overwetted areas are predominate, which indicates the destruction of the drainage network. On the NDVI map (Fig. 4 e), the values of the vegetation cover indicator are too high for agricultural crops – from 0,8 to 0,9, which indicates that the land is overgrown with shrubs.

In order to verify the satellite data, on-situ surveys within the studied plot of the Irpin DMS were carried out (Fig. 5). The photos show large craters from the shells, which over time become overgrown with grass. Therefore, it is necessary to carry out such surveys in a timely manner, because the landscape changes with time. The photos show the destruction of the drainage network and the fragments of the tile drainage.

According to the results of the analysis of high spatial resolution images acquired on March 21, 2022 and April 15, 2022, and field surveys within the studied plot, the territory was classified according to the damage caused by explosive craters, which made it possible to build damages maps (Fig. 6). We have proposed a separate degree of the territory damages by the percentage of the area of craters within the plots: 0–10 % – slightly affected, 10–30 % – moderately affected, more than 30 % – strongly affected area.

As a result of the conducted monitoring, it was determined that on the image dated April 21, 2022, the area of severe damage is 130 hectares, which is 28 % of the total area of the research plot; the area of moderate damage is 139 hectares, which is 29 % of the plot; the area of slight damage is 197 hectares, which is 43 % of the plot. On the image dated April 15, 2022, the area of severe damage is 229 hectares, which is 49 % of the plot; the moderate affected area is 237 hectares, which is 51 % of the plot.

So, it can be noted that the determined necessary set of indicators – spectral indices and the combination of RSR bands is an effective mean of assessing the state of water bodies and reclaimed lands that have been affected by military actions. The proposed approach can be further developed into a separate methodology for monitoring water bodies and reclaimed lands.

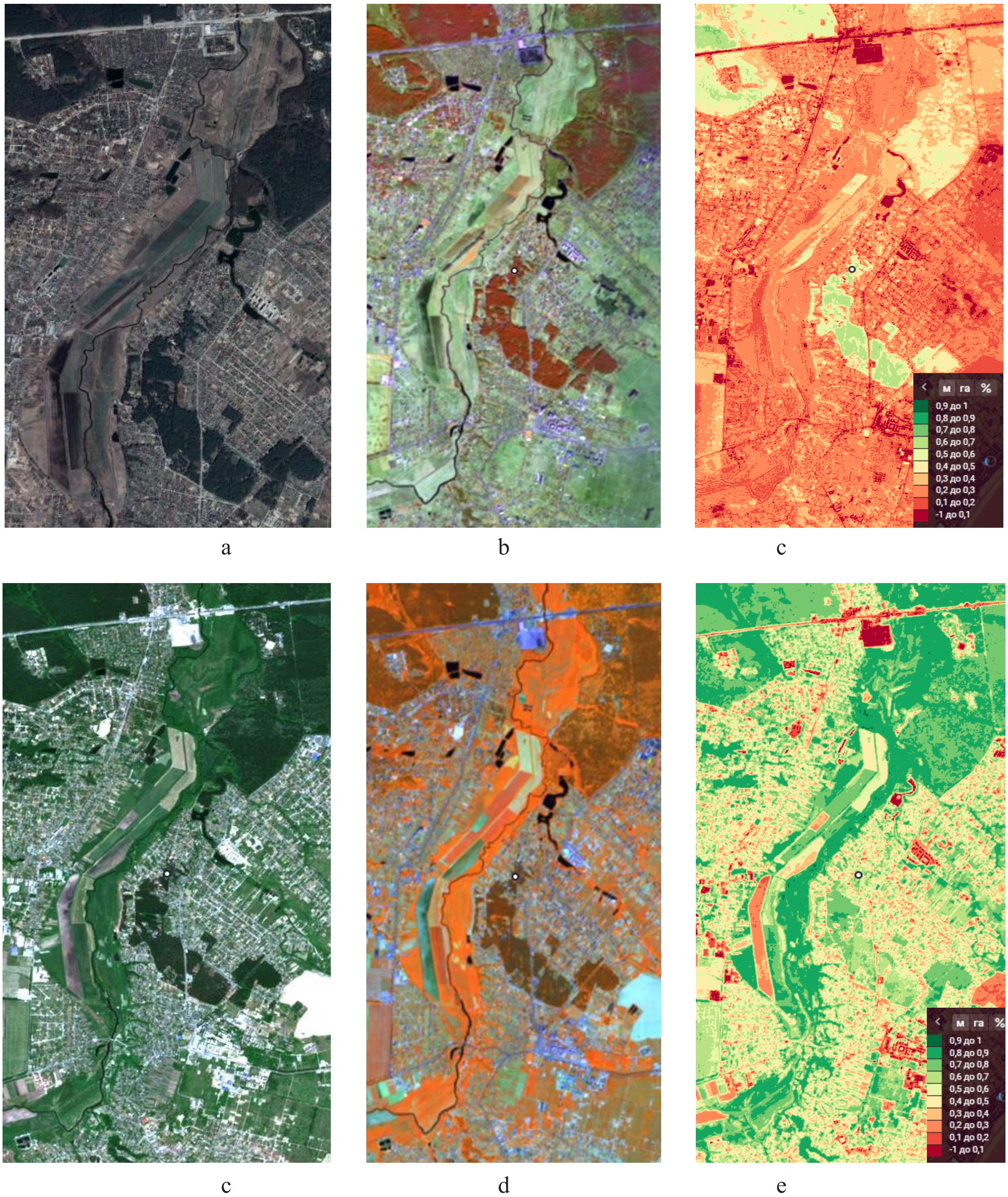


Fig. 4. Airbus image and maps of calculated spectral indices based on Sentinel-2 L2A images: a – Airbus image dated 04.15.2022 with shell craters, b – combination of RSR bands of the Sentinel-2 L2A image (23.03.2023), c – NDVI vegetation index (March 23, 2022); d – Sentinel-2 L2A image of plot restoration (01.06.2023), d – Sentinel-2 L2A RSR bands combination (01.06.2023), e – Sentinel-2 L2A NDVI vegetation index (01.06. 2023)

a b

c d

Fig. 5. Consequences of military actions in the area of the Irpinska DMS:
a – a crater from a shell, shown on a satellite image (see Fig. 4 a); b – grass overgrowth of the craters over time; c – closed drainage network damaged by explosions; d – fragments of tile drainage (photos by A. Shevchenko)

a b

Fig. 6. Maps-schemes of the area of the Irpinska DMS that was damaged in the result of military actions: a – due to the conduct of military actions, b – overgrowth of the area with vegetation

Conclusions. It was established that the integrated application of spectral indices in their certain combination and comparison makes it possible to monitor water bodies and reclaimed lands. The comparison of processed satellite data (images) at different moments of time made it possible to follow the progress of flooding of the floodplain of the Irpin river, which was caused by the destruction of the hydraulic facility in Kozarovichi village. The applied method makes it possible to solve a number of problems, in particular, to quickly diagnose the flooded area, to quantify the areas that are flooded or polluted by sediments, to predict the possible consequences of the impact on reclaimed lands.

A comparative analysis of the state of reclaimed lands before and after military actions using high-resolution satellite images makes it possible to determine the extent of damage of the territory by shells, mines, and aerial bombs, and to create maps-shemes based on the degree of damage of reclaimed lands, which indirectly indicate the degree of destruction of canals, closed drainage networks, etc.

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МОНІТОРИНГ ВОДНИХ ОБ'ЄКТІВ І МЕЛІОРОВАНИХ ЗЕМЕЛЬ, ЩО ЗАЗНАЛИ ВПЛИВУ БОЙОВИХ ДІЙ ЗА СУПУТНИКОВИМИ ДАНИМИ

О.В. Власова, докт. с.-г. наук, А.М. Шевченко, канд. с.-г. наук, І.А. Шевченко, канд. техн. наук, О.М. Козицький

[1] Інститут водних проблем і меліорації НААН, Київ, Україна;
https://orcid.org/0000-0002-1911-4329$ e-mail: elena_vl2001@ukr.net;
[2] Інститут водних проблем і меліорації НААН, Київ, Україна;
https://orcid.org/0000-0002-2637-6538$ e-mail: monitoring_protect@ukr.net;
[3] Інститут водних проблем і меліорації НААН, Київ, Україна;
https://orcid.org/0000-0002-7401-8786$ e-mail: irashef@ukr.net;
[4] Інститут водних проблем і меліорації НААН, Київ, Україна;
https://orcid. org/0000-0002-4459-6331$ e-mail: olegkoz@ukr.net;

Анотація. *У статті викладено результати спостережень за станом водних об'єктів і меліорованих земель, які зазнали впливу бойових дій, за допомогою супутникових знімків різного просторового розрізнення, комбінації їх каналів та натурних спостережень. Визначення оптимального* *набору показників – спектральних індексів та комбінацій каналів супутникових знімків для ведення моніторингу водних об'єктів і меліорованих земель, які зазнали впливу бойових дій, є метою досліджень. На прикладі затоплення заплави р. Ірпінь водами Київського водосховища унаслідок руйнування водопропускної споруди підраховано зміну площі затоплення на основі карт спектральних індексів NDWI, NDSI та класифікації поверхні за знімками Sentinel-2 L2A при комбінації каналів Red8, SWIR1, Red (RSR). За цією методикою було вирішено актуальне завдання з виокремлення поверхневих вод і суходолу та фіксації зміни площі затоплення протягом періоду березень 2022 р. – травень 2023 р. Інше масштабне затоплення після підриву греблі на Каховській ГЕС 6 червня 2023 р. було досліджено на території вздовж річок Дніпро та Козак біля с. Отрадокам'янка в Херсонській області. На основі знімків Sentinel-2 L2A отримано карти індексів SAVI та NDWI, за якими виявлено місця ураження ґрунтового покриву наносами та збільшення площ водних об'єктів за період 05.06 – 18.06.2023 р. Необхідно зазначити, що з часом вздовж узбережжя вітрова ерозія може спричинити міграцію важких металів з пилом. Моніторинг меліорованих земель, що зазнали впливу бойових дій, проведено у заплаві р. Ірпінь на Ірпінській осушувально-зволожувальній системі у межах Білогородської територіальної громади Бучанського району Київської області протягом трьох часових інтервалів: до бойових дій у 2019 р. (використано NDVI, коефіцієнт ir/r, індекс оксиду заліза IO), навесні 2022 р. та після боїв у 2023 р. (використано RSR, NDVI). У першому випадку встановлено задовільний стан меліорованих земель, у другому – зафіксовано вирви від снарядів та руйнацію дренажної системи. Було виявлено, що протягом третього періоду превалюють перезволожені ділянки. Це підтверджує руйнацію дренажної мережі. Розраховані значення індексу NDVI виявилися занадто високими для сільгоспкультур, що вказує на заростання угідь чагарником. За результатами проведеного моніторингу здійснено класифікацію території за ступенем її ураженості вибуховими воронками з виокремленням: (0–10 %) слабо уражених, (10–30 %) середньо уражених і сильно уражених (понад 30 %) ділянок. Запропонований підхід у подальшому може бути розвинуто в окрему методологію ведення моніторингу водних об'єктів і меліорованих земель. Оцінювання стану водних об'єктів і меліорованих земель, які зазнали впливу бойових дій, рекомендовано здійснювати за комплексом спектральних індексів, комбінації каналів знімків та натурних спостережень.*

Ключові слова: *водні об'єкти, меліоровані землі, бойові дії, супутникові знімки, спектральні індекси, ступінь ураження*

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SHALLOW AND COMBINED TILLAGE OF BLACK SOIL TYPICAL AT DIFFERENT SPECIALISATION IN AGRICULTURAL PRODUCTION IN THE LEFT BANK FOREST STEPPE OF UKRAINE

Yu.O. Tarariko[1], Dr. of Agricultural Sciences, P.V. Pysarenko[2], Dr. of Agricultural Sciences, R.V. Saydak[3], Ph.D. in Agricultural Sciences, Yu.V. Soroka[4], Ph.D. in Agricultural Sciences, R.V. Olepir[5], Ph.D. in Agricultural Sciences, Z.V. Shcherbyna[6], Ph.D. in Agricultural Sciences, O.P. Vdovychenko[7], Ph.D. student

[1] Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences, Kyiv, Ukraine;
https://orcid.org/0000-0001-8475-240X; e-mail: urtar@bigmir.net;
[2] Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences, Kyiv, Ukraine;
https://orcid.org/0000-0002-2104-2301; e-mail: Pavel_Pisarenko74@ukr.net;
[3] Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences, Kyiv, Ukraine;
https://orcid.org/0000-0002-0213-0496; e-mail: saidak_r@ukr.net ;
[4] Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences, Kyiv, Ukraine;
https://orcid.org/0000-0001-6228-4131; e-mail: soroka_Yu@bigmir.net;
[5] Poltava State Agrarian University, Poltava, 04047, Ukraine;
https://orcid.org/0000-0002-0825-7914; e-mail: roman.olepir@pdaa.edu.ua;
[6] Breeding and Genetic Institute – National Center of Seed Science and Varietal Research of the National Academy of Agrarian Sciences, Odessa, Ukraine;
https://orcid.org/0000-0002-4630-8372; e-mail: zoyasgi09@ukr.net;
[7] Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences, Kyiv, Ukraine;
https://orcid.org/0009-0007-0557-0036; e-mail: alex.ucccf@gmail.com

Abstract. *The article presents the results of long-term experimental studies on the effect of different methods of main tillage on soil fertility and crop productivity when applying different degrees of fertilization. Field research was conducted during 2013–2020 on the lands of the Poltava Research Station of the Institute of Pig Breeding and Agro-Industrial Production of the National Academy of Agricultural Sciences. It has been established that the systematic use of organic and organic and-mineral fertilization systems improves the nutrient regime of typical black soil with differentiation of the arable layer by the amount of phosphorus and potassium when applying long-term minimal loosening. There is a tendency towards an increase in density in the layers of 20–40 and 40–60 cm when applying systematic shallow tillage, where this indicator exceeds the upper limit of the optimal range of 1.0–1.3 g/cm³. Application of manure and mineral fertilizers compared to surface loosening makes it possible to additionally annually sequester 0.3–0.4 t/ha of carbon, which is equivalent to 1.2–1.6 t of carbon dioxide. By the average multi-year yield of corn per silage, shallow loosening is inferior to combined tillage by an average of 10 %. Tendencies to a decrease in the average long-term productivity of soybean, spring barley, and pea crops when using minimal tillage compared to the combined one are manifested only in certain fertilizer options. Under optimal conditions of heat and moisture supply, the ratio of grain and straw in soybeans decreases. On winter wheat, after peas, there is a tendency towards the preference of shallow loosening. The ratio of wheat grain to straw increases significantly under favorable conditions. Corn responds better to the combined tillage system, which prevails shallow loosening in terms of grain yield by the fertilizer options by 6–10 %. Under favorable conditions, the ratio of stems to grain increases significantly, especially on fertilized grounds. From the studied crops, the productivity of sugar beets fluctuates to a greater extent in relation to the conditions of the year, and to a lesser extent – winter wheat, grown after peas and corn for grain. By the average long-term crop productivity, shallow tillage is inferior to combined tillage by 4–8 % having a confidence level as 5 %. When applying manure, it is advisable to use a combined system of soil tillage, for plant-oriented agrarian production, it is economically advisable to use surface loosening for all crops.*

Key words: *soil tillage, fertilizers, specialization, agricultural production, crop rotation, moisture supply, productivity, efficiency*

Relevance of research. Agriculture is a land use that inevitably leads to the greatest soil loss on all continents and in all climates [1, 2]. Soil degradation is recognized as a serious problem of the 21st century worldwide in the global agroecosystem [3]. Increasing soil degradation threatens agricultural production and food supply for the growing population in developing countries and regions [4, 5]. The basic cultivation plays not the last role in the degradation processes. The analysis of global trends in this area indicates a gradual elimination of deep moldboard tillage in favor of shallow or surface tillage. The transition from plowing to shallow tillage includes a reduction in the depth of the basic cultivation, the absence of direct soil overturning, and a change in energy consumption. All this affects the physical characteristics and functioning of the soil [6].

Along with this, it is well known that modern climate changes have a negative impact on the moisture supply of soils, and this factor limits the use of their fertility potential. Also, scientific research and practical experience have proven that irrigation is the most effective measure to prevent this impact. However, given the significant shortage of water resources in Ukraine, widespread irrigation is problematic. Under such conditions, regulation of the water-air regime of soils is carried out by other agrotechnical measures, in particular, soil cultivation systems. Therefore, the issue of controlling soil processes under the effect of minimal and differentiated tillage systems, taking into account their influence on moisture accumulation, is relevant.

Analysis of recent research and publications. The main task of soil cultivation in modern agriculture is to create optimal conditions for sowing, further growth and development of agricultural crops [7, 8]. At the same time, to increase the profitability of production activity, it is important to reduce the costs of chemical and technological resources without reducing crop yield and the productivity of crop rotations [9, 10]. Therefore, special attention is currently being paid to the issue of improving existing and developing new energy-saving cultivation technologies, taking into account their impact on agrochemical, water-agrophysical, physicochemical and other soil properties [11].

In the agricultural system, tillage is one of its effective components in view of combating various harmful organisms, particularly weeds [12–15]. They are closely related to erosion processes and the intensity of mineralization of soil organic matter [16–20]. Rational tillage of the soil improves the supply of cultivated plants with elements of mineral nutrition, moisture, and it largely determines the final productivity of agrocenoses [21–23].

Solving many issues related to soil cultivation largely depends on the physical and mechanical properties of the soil, and in particular the soil compaction density. The physical parameters of the soil should be as close as possible to the optimal ones, that is, those that provide the best conditions for plant development. Increased soil density negatively affects the processes of gas exchange between the soil and the atmosphere, assimilation and evaporation of moisture [24–26].

If there is optimal soil density of the sowing layer before sowing and in the initial phases of development, agricultural crops form the maximum yield. Therefore, the prerequisite for reducing the intensity of mechanical loosening, in particular, the application of the "No-Till" system, is achieving such a state when the equilibrium density of the soil corresponds to the characteristics and requirements of the cultivated crop [27, 28]. Therefore, the problems related to the determination of the optimal system of soil cultivation in crop rotation, taking into account the specific features of soil and climatic conditions, production specialization and fertilization systems are relevant. In this regard, the study of the long-term impact of different cultivation systems on the properties of typical black soil and the productivity of the main crops grown on it in the Left Bank Forest Steppe of Ukraine is practical and scientific interest.

The purpose of the research is to establish the dynamics of the changes in the properties of typical black soil, the crop yield and the productivity of crop rotation typical for the Left Bank Forest Steppe under the influence of minimal and combined tillage systems against the background of organic and organo-mineral fertilization systems that correspond to crop or livestock specialization of agricultural production.

Research materials and methods. To analyze the practicability of minimizing tillage, the information base of the long-term stationary field experiment of the Poltava Experimental Station of the Institute of Pig Breeding and Agro-Industrial Production of the National Academy of Agricultural Sciences of Ukraine "The effect of systematic application of fertilizers when applying various types of tillage on crop productivity and quality as well as soil fertility" was used. The field experiment was made in 1987. The soil was a typical black soil with a humus content of 5 %, low availability with plant-available nitrogen compounds, medium availability with phosphorus and high availability with potassium.

Soil samples were taken in accordance with DSTU [29], namely: the content of organic matter in the soil, total nitrogen, mobile compounds of phosphorus and potassium [30, 31, 32] and soil density [33]. Analytical study of the soil was carried out in the agrochemical laboratory of the Poltava Research Station of the Institute of Pig Breeding and Agro-Industrial Production of the NAAS.

Crop rotation included corn for silage, winter wheat, soybeans, sugar beet, spring barley, peas, winter wheat and corn for grain.

The following basic tillage systems were studied: combined (plowing for row crops, surface tillage to the depth of sowing with a combined unit for other crops); shallow boardless tillage (surface tillage to the sowing depth with a combined unit for all crops). The fertilization systems were the following (Table 1): without fertilizers – reference area (RA); manure 10 t/ha (M); manure + $N_{52}P_{52}K_{52}$ (M+NPK); by-products (BP); by-products +NPK (BP+NPK).

The coefficient of variation was used to estimate the range of fluctuations in crop yields and productivity of crop rotations by years. The estimated variation coefficient of the studied indicator can be grouped by the accepted scale of qualitative assessment: less than 15 % is low; 15–30 is medium; more than 30 is high.

Research results. First of all, it should be noted that at the time of the experiment was started, the content of easily hydrolyzable nitrogen compounds, available phosphorus, and exchangeable potassium in the 0–20 cm soil layer averaged 155, 70, and 152; in the 20–40 cm soil layer it was 137, 58 and 124 mg/kg respectively. Over the years of conducting research, the improvement of the nutrient regime of typical black soil on all fertilization grounds was recorded, especially when applying the minimal system of basic cultivation, where soil nitrogen content has changed from low to medium, for phosphorus and potassium – to high and very high.

One of the negative consequences of applying minimal or zero tillage systems can be soil over-compaction. This leads to oversaturation of the upper layers with moisture, which can cause a lack of oxygen for the roots. Under anaerobic conditions, denitrification can lead to significant losses of nitrogen to the atmosphere. In case of overcompaction detection, the expected economic effect of its elimination is significant, and the increase in yield can reach 20 %. The optimal value of soil density (bulk mass) of the soil for most agricultural crops is 1.0–1.3 g/cm^3, and when the density is higher than the optimal by 0.1 g/cm^3, the grain yield decreases by 10–30 % [34].

Study on the effect of fertilization and tillage systems on the agrophysical properties of typical black soil has not established reliable changes in the equilibrium density of the soil arable layer, which fluctuated between 1.30–1.35 g/cm^3 by the experiment variants. There is a tendency towards an increase in the compaction density in layers of 20–40 and 40–60 cm when applying systematic shallow tillage, where this indicator also exceeds the upper optimal limit of 1.0–1.3 g/cm^3 for all fertilization variants except the reference area. This may be due to the formation of various moisture reserves deeper than 20 cm during the long-term applying the investigated soil loosening methods, and also it was possible due to the formation or destruction of the tillage pan.

If traditional and minimal tillage systems have different effects on the agrophysical parameters of typical black soil, then we can make assumptions about changes in its other properties over time [35]. Thus, it was established that tillage systems did not reliably affect the amount of nitrogen and phosphorus in the 0–20 cm layer. At the same time, it can be seen from Figure 1 that when minimizing loosening, there is a tendency to the decrease in the amount of these nutrients in the 20–40 cm layer. Only the content of exchangeable potassium when applying shallow tillage in the lower part of the profile is higher, which is obviously can be explained by its greater mobility compared to phosphorus.

On fertilized grounds, differentiation of the upper part of the soil profile was traced by the total phosphorus content. When applying plowing, its amount is higher in the deeper 20–40 cm layer, and lower in the upper 0–20 cm layer compared to surface loosening. Such trends were not found for total nitrogen.

All this may indicate that in view of the hydrothermal conditions of the year and biological characteristics of individual crops, their yield may also depends on the technology of soil cultivation and the location of nutrients.

When applying both investigated tillage systems, humus reserves in the 0–40 cm layer in the reference area without fertilizers amount to 277 t/ha. At first glance, it seems that the systematic application of manure is accompanied by an increase in the amount of organic matter (Fig. 2). It seems logical that the organo-mineral fertilization system contributes to the increase in crop yield and thanks to the additional accumulation of root and post-harvest residues the humus condition of the typical black soil significantly improves, especially when applying

1. Scheme of fertilization of agricultural crops in crop rotation

Fertilization systems	Corn for silage			Winter wheat			Soy			Sugar beet				Spring barley			Peas			Winter wheat			Corn for grain			
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	Manure, t/ha	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	Manure, t/ha	N	P_2O_5	K_2O
without fertilizers – reference area (RA)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
manure 10 t/ha (M)	–	–	–	–	–	–	–	–	–	40	–	–	–	–	–	–	–	–	–	–	–	–	30	–	–	–
manure + $N_{52}P_{52}K_{52}$ (M + NPK);	60	45	45	45	45	45	–	15	15	40	140	140	155	30	30	30	–	15	15	45	45	45	30	30	45	45
By-products (BP)	50	–	–	–	–	–	25	–	–	–	40	–	–	210	–	–	25	–	–	30	–	–	–	45	–	–
By-products+NPK (BP+NPK)	60	45	45	45	45	45	–	15	15	–	140	140	155	30	30	30	–	15	15	45	45	45	–	30	45	45

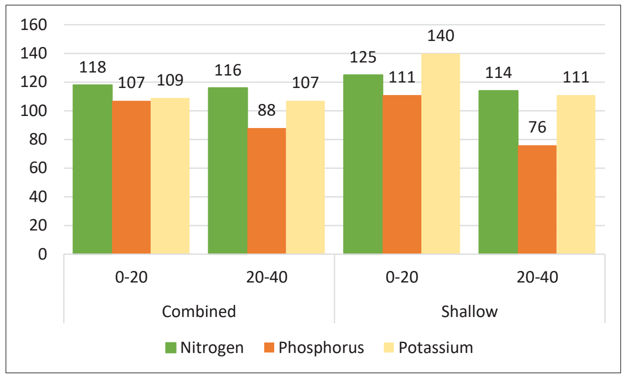

Fig. 1. The effect of tillage systems on the nutrient content in typical black soil when systematically applying manure and mineral fertilizers, mg/kg (2013–2020)

a combined tillage system. However, balance studies indicate that during the crop rotation without applying fertilizers, humus reserves in the 0–40 cm layer decreased by 5 t/ha, that is, the initial level of this indicator was 282 t/ha.

Therefore, the manure fertilization system when applying shallow tillage does not ensure the reproduction of the humus state of the typical black soil; when applying the combined one, the humus reserves are kept at the initial level. On the grounds where manure is supplemented with mineral fertilizers, organic matter reserves are stabilized when applying surface loosening and accumulated (5 t/ha) when applying the organo-mineral fertilization system. In the latter case, it can be explained by the formation of better conditions for humification processes with a more uniform distribution of organic biomass with a small ratio of nitrogen and carbon along the profile of the upper plowed layer.

Similar, but due to the greater C/N ratio, stronger orientation of the processes of transformation of fresh organic mass is more pronounced when applying crop by-products as fertilizer. In this regard, it is only necessary to emphasize the equivalence the methods of loosening.

As a result, it can be considered that cultivation methods under certain conditions make it possible to effectively deposit atmospheric carbon in the soil. For example, plowing of manure and mineral fertilizers compared to surface loosening makes it possible to additionally annually sequester 0.3–0.4 t/ha of carbon, which is equivalent to 1.2–1.6 t of carbon dioxide. It is clear that such a factor must be taken into account when assessing the practicability of applying soil cultivation technologies.

Therefore, the minimization of soil cultivation is accompanied by changes in its various parameters, which in turn should obviously lead to the fluctuations in the yield of individual crops compared to the traditional combined tillage system, especially in relation to variable agrometeorological factors. That is, in some specific conditions of a particular year, one system may prevail in favor of growing a certain crop, in others – another. To determine such features of the studied cultivation technologies, the following were compared: the average long-term and maximum yield in the most favorable year of 8 crops on 5 fertilization grounds; the multiplicity of crop productivity growth as a result of the combined effect from applying the methods of loosening and fertilizers compared to the natural ground of fertility.

The analysis of the research results showed that both by the average multi-year and maximum yield of corn per silage, shallow loosening is inferior to the combined tillage by 10 % on average on the variants of experiment. Multiplicity of increase in the average crop yield when applying fertilizers for both loosening methods is 1.2 times. In favorable growing conditions, applying fertilizers increases the yield of green mass only when applying the combined tillage. On all fertilizer variants, when applying shallow loosening in favorable conditions the crop productivity increases to the average long-term one (Table 2).

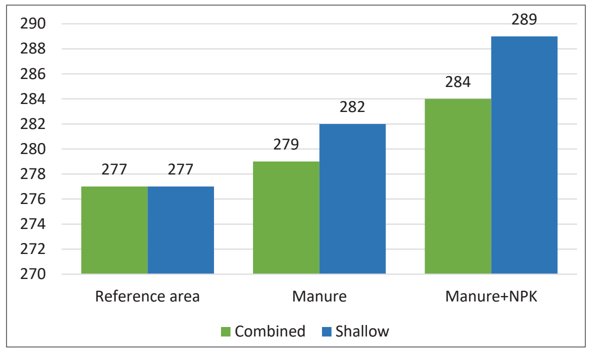

Fig. 2. The effect of fertilization and tillage systems on humus reserves in the 0–40 cm layer of typical black soil, t/ha (2013–2020)

On winter wheat, after corn for silage, there is also a tendency to the decrease in the yield when applying shallow tillage (Table 3). Compared to the other fertilization systems, the multiplicity of rise of both medium and high yields compared to the reference area without applying fertilizers did not depend on tillage; it was the lowest with long-term manure application and amounted to 1.1–1.2 times, on other variants – 1.5–1.6 times.

On the contrary, the ratio of high yield in a favorable year and average multi-year yield (1.6–1.7) is larger when applying manure, which indicates an increase in its efficiency in near-optimal hydrothermal conditions. In general, it can be noted that under all investigated fertilization systems, winter wheat responses poorly to cultivation methods, so, to reduce the cultivation costs, it is advisable to use shallow loosening during its cultivation.

From a technological point of view, an important indicator is the ratio of straw to grain,

2. The effect of tillage methods on the yield of corn for silage under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	**Manure**	**Manure + NPK**	**BP**	**BP+NPK**
Average, t/ha	Combined	30.8	35.8	40.1	38.2	39.5
	Shallow	29.0	32.0	35.4	33.6	36.4
	Difference, %	–7	–13	–15	–8	–3
Multiplicity of yield growth compared to the reference area	Combined	–	1.2	1.3	1.2	1.3
	Shallow	–	1.1	1.2	1.2	1.3
Maximum, t/ha	Combined	65.1	75.0	82.1	70.5	74.6
	Shallow	69.6	65.2	70.1	65.1	72.3
	Difference, %	–6	–10	–12	–12	–8
Multiplicity of yield growth compared to the reference area	Combined	–	1.2	1.3	1.1	1.1
	Shallow	–	0.9	1.0	0.9	1.0
Maximum compared to average, multiplicity	Combined	2.3	1.8	1.7	1.7	1.8
	Shallow	2.4	2.0	2.0	1.9	2.0

3. The effect of tillage methods on the yield of winter wheat after corn under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure + NPK	BP	BP + NPK
Average, t/ha	Combined	2.2	2.5	3.5	3.2	3.6
	Shallow	2.2	2.4	3.4	3.1	3.4
	Difference, %	–2	–5	–3	–2	–4
Multiplicity of yield growth compared to the reference area	Combined	–	1.1	1.6	1.5	1.6
	Shallow	–	1.1	1.6	1.5	1.6
Maximum, t/ha	Combined	3.7	4.8	5.6	5.4	5.9
	Shallow	3.7	4.5	5.6	5.3	5.7
	Difference, %	0	–6	0	–1	–5
Multiplicity of yield growth compared to the reference area	Combined	–	1.3	1.5	1.5	1.6
	Shallow	–	1.2	1.5	1.4	1.5
Maximum compared to average, multiplicity	Combined	1.7	1.9	1.6	1.7	1.7
	Shallow	1.7	1.9	1.6	1.7	1.6

which is used for making balance calculations. By the average long-term yield data, this indicator varied between 1.3 and 1.4 depending on the fertilization and tillage variants. However, under favorable conditions of the most productive year, this ratio significantly gets bigger and is 2.3–2.4 in the reference area, 1.8–2.0 – when applying manure and by-products, and 1.5–1.8 – when applying organo-mineral fertilization system.

On sugar beet, we also note a tendency to decrease both average and maximum productivity in a favorable year when applying shallow loosening of soil; on average it is 10 % on the fertilization variants (Table 4). At the same time, it should be noted that during the long-term use of crop production waste for fertilizer, this negative effect grows significantly weaker, and in near-optimal conditions of heat and moisture supply, it is completely eliminated. The average long-term root yield growth factor when applying manure compared to the reference area is 1.2–1.3 and 1.6–1.8 on the other fertilizer variants. This also indicates the leveling effect of fertilizers on the negative impact of shallow tillage. In favorable hydrothermal conditions, similar, but less pronounced patterns can

4. The effect of tillage methods on sugar beet yield under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure+ NPK	BP	BP+NPK
Average, t/ha	Combined	25.4	31.3	40.1	39.5	41.6
	Shallow	21.3	26.8	35.8	36.9	38.2
	Difference, %	–16	–14	–11	–7	–8
Multiplicity of yield growth compared to the reference area	Combined	–	1.2	1.6	1.6	1.6
	Shallow	–	1.3	1.7	1.7	1.8
Maximum, t/ha	Combined	37.6	42.8	52.7	50.5	52.9
	Shallow	35.4	39.8	43.4	53.8	53.6
	Difference, %	–6	–7	–18	7	1
Multiplicity of yield growth compared to the reference area	Combined	–	1.1	1.4	1.3	1.4
	Shallow	–	1.1	1.2	1.5	1.5
Maximum compared to average, multiplicity	Combined	1.5	1.4	1.3	1.3	1.3
	Shallow	1.7	1.5	1.2	1.5	1.4

5. The effect of tillage methods on soybean yield under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure + NPK	BP	BP + NPK
Average, t/ha	Combined	1.2	1.4	1.7	1.5	1.6
	Shallow	1.2	1.3	1.7	1.6	1.7
	Difference, %	3	–7	–1	3	9
Multiplicity of yield growth compared to the reference area	Combined	–	1.2	1.5	1.3	1.3
	Shallow	–	1.1	1.4	1.3	1.4
Maximum, t/ha	Combined	1.9	2.2	3.1	2.6	2.3
	Shallow	2.2	2.7	2.8	3.1	2.8
	Difference, %	17	19	–10	21	18
Multiplicity of yield growth compared to the reference area	Combined	–	1.2	1.6	1.3	1.2
	Shallow	–	1.2	1.2	1.4	1.2
Maximum compared to average, multiplicity	Combined	1.6	1.6	1.8	1.7	1.5
	Shallow	1.9	2.0	1.6	2.0	1.6

be noted. Comparing the root yield in such conditions with the average long-term indicator, it can be noted a higher multiplicity of growth on the variant without fertilizers, which also indicates an increase in the efficiency of the sugar beet plants' use of the natural fertility in favorable weather conditions.

Tendencies to a decrease in the average long-term productivity of soybean crops when applying minimal tillage compared to the combined tillage are manifested only on certain fertilizer variants (Table 5).

In favorable conditions of the most productive year, the positive effect of soil loosening minimization on crop yield compared to the traditional technology is mostly noted. Multiplicity of growth compared to the reference area for different variants of fertilization and tillage fluctuates significantly, which can be caused by other factors of plant growth and development. In favorable hydrothermal conditions when having natural soil fertility, as well as when applying organic fertilizer systems under soybeans for a long time, it is advisable to use the shallow tillage, while when applying organo-mineral fertilization systems it is more reasonable, to use the combined one.

By the long-term yield data, the grain-to-straw ratio on the investigated variants is mostly 1.4 with a tendency to its increase shallow tillage, in particular when applying by-products for fertilizer constantly (1.6). In contrast to previously described winter wheat and sugar beets, in close to optimal conditions of heat and moisture supply, the ratio of grain and straw in soybeans does not increase, but, on the contrary, decreases to 0.9–1.2.

The response of spring barley, which is considered to be an indicator crop in crop rotation, to the tillage methods is ambiguous. Based on the average long-term data on its yield, it is possible to note the advantage of the combined tillage when applying organic fertilization systems (Table 6). This is obviously related to the more uniform mixing of organic biomass of by-products with the soil and the formation of a better nutritional regime as it decomposes.

In the conditions of the most productive year with active microbiological processes in the soil, combined loosening has an advantage only on the variants with manure application, which indicates the need to plow it after application. That is also proven by the fact that the multiplicity of barley grain yield growth when applying manure fertilization systems is always significantly lower when applying shallow tillage. Moreover, the degree of crop yield growth in favorable conditions compared to average data is also significantly higher when manure is plowed.

In most studied variants, the ratio of barley grain to straw fluctuates at the level of 1.3–1.4. It is also possible to note a tendency towards a slight increase of this indicator in close to optimal hydrothermal conditions. Both by the average multi-year yield data for peas and by the data of the most productive year, it is possible to note a tendency towards the prevailing (by 5–10 %) of the combined tillage over the shallow one on almost all fertilizer variants (Table 7).

6. The effect of tillage methods on spring barley yield under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure+ NPK	BP	BP+NPK
Average, t/ha	Combined	1.7	2.2	2.7	2.6	2.7
	Shallow	1.7	2.0	2.7	2.5	2.7
	Difference, %	1	–9	–1	–5	0
Multiplicity of yield growth compared to the reference area	Combined	–	1.3	1.6	1.5	1.6
	Shallow	–	1.1	1.5	1.5	1.6
Maximum, t/ha	Combined	3.0	4.5	4.9	4.6	4.7
	Shallow	3.2	3.2	4.6	5.0	4.7
	Difference, %	9	–28	–7	8	0
Multiplicity of yield growth compared to the reference area	Combined	–	1.5	1.7	1.6	1.6
	Shallow	–	1.0	1.4	1.6	1.5
Maximum compared to average, multiplicity	Combined	1.7	2.0	1.8	1.8	1.7
	Shallow	1.9	1.6	1.7	2.0	1.7

7. The effect of tillage methods on peas yield of under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure+ NPK	BP	BP + NPK
Average, t/ha	Combined	2.4	2.6	3.0	2.8	2.8
	Shallow	2.2	2.5	2.7	2.6	2.7
	Difference, %	–6	–6	–10	–5	–7
Multiplicity of yield growth compared to the reference area	Combined	–	1.1	1.2	1.2	1.2
	Shallow	–	1.1	1.2	1.2	1.2
Maximum, t/ha	Combined	3.9	5.1	4.6	4.0	4.4
	Shallow	3.3	4.9	4.1	4.0	4.2
	Difference, %	–15	–4	–10	0	–3
Multiplicity of yield growth compared to the reference area	Combined	–	1.3	1.2	1.0	1.1
	Shallow	–	1.5	1.3	1.2	1.3
Maximum compared to average, multiplicity	Combined	1.6	1.9	1.6	1.5	1.5
	Shallow	1.5	2.0	1.6	1.5	1.6

The average productivity of this crop is almost independent of the fertilization system, with the exception of the aftereffect of applying manure with a significant negative difference compared to other fertilizer variants, where the growth factor of crop productivity is 1.2 compared to the reference area. At the same time, it is rather difficult to explain why, in a favorable year, a significantly higher grain yield was obtained under this fertilization system compared to other variants. Accordingly, the increase in the productivity of peas from the optimization of growing conditions when applying the organic fertilization system with manure reaches 100 % against 50–60 % on other variants.

The ratio of peas grain to straw by the average multi-year yield data is mostly 1.1 with a range of 1.0–1.3. In a favorable year, there is a tendency to increase this indicator to 1.3–1.5, excluding the organic system with manure – 1.1.

Unlike other crops, winter wheat after peas both by the average and high yields practically does not respond to the tillage system for all fertilizer variants (Table 8).

As in the case of peas, the organic system with manure is distinguished from other variants by significantly lower yield and crop growth rate

8. The effect of tillage methods on winter wheat and peas yield of under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure+ NPK	BP	BP+NPK
Average, t/ha	Combined	3.0	3.4	3.9	3.8	3.8
	Shallow	3.2	3.4	3.9	3.9	3.9
	Difference, %	6	0	1	2	2
Multiplicity of yield growth compared to the reference area	Combined	–	1.1	1.3	1.3	1.3
	Shallow	–	1.1	1.2	1.2	1.2
Maximum, t/ha	Combined	5.1	5.2	5.6	5.7	5.2
	Shallow	5.0	5.5	5.7	5.6	5.9
	Difference, %	–3	7	1	–1	12
Multiplicity of yield growth compared to the reference area	Combined	–	1.0	1.1	1.1	1.0
	Shallow	–	1.1	1.1	1.1	1.2
Maximum compared to average, multiplicity	Combined	1.7	1.5	1.5	1.5	1.4
	Shallow	1.5	1.6	1.5	1.4	1.5

compared to the reference area. It is obvious that under the favorable conditions of the most productive year, the positive effect of peas as a forecrop results in a high yield in the reference area and a low coefficient of its growth under almost all investigated fertilization systems. At the same time, the role of near-optimal conditions is manifested in a significant increase in the productivity of wheat crops compared to the average long-term indicators, which in turn indicates the low frequency of such conditions.

The assessment of the grain-to-straw ratio by the average long-term yield data shows that the systematic application of the entire low-value part of crops as fertilizer can contribute to the increase of this indicator from 1.3–1.4 to 1.4–1.5, and in close to optimal conditions even up to 1.7–2.2. There is also a tendency to increase this ratio when applying shallow tillage.

Unlike the other crops, all studied fertilization systems have a lesser effect on the yield of corn per grain (Table 9). The multiplicity of its growth compared to the reference area is 1.1–1.2, which is obviously related to biological features and the ability to more fully use the available soil and climatic potential.

Corn responds better to the combined tillage, which prevails in terms of grain yield, shallow loosening on the fertilizer variants by 6 – 10 %. In near-optimal conditions of the most productive year, this advantage is preserved only when applying manure fertilization systems. In such conditions, on the soils with natural fertility, on the contrary, when applying shallow tillage, the productivity of corn is 10 % higher than when applying the combined one, 8.1 versus 7.4 t/ha, respectively. The multiplicity of crop yield growth in a favorable year compared to the average multi-year yield data turned out to be higher when applying shallow loosening for all investigated fertilization systems.

When having the average multi-year yield of corn, the ratio of grain to stalks on the fertilizer variants in most cases is 1.7. In favorable conditions of the most productive year, this indicator increases to 2.1. In the reference area without fertilizers, as well as under the organic and mineral fertilization system with plowing crop by-products, the ratio is 2.6 and 2.5, respectively, with a tendency to decrease it when applying shallow tillage.

As the previously presented research results show, the crop yields fluctuate significantly under the influence of various factors. In particular, the effect of the studied fertilization and tillage systems on individual crops is completely different, especially in different conditions.

A variation coefficient was used to estimate the range of fluctuations in crop yield and productivity of crop rotation by year. The fluctuations in crop yield data over time in studied variants in view of applying fertilization systems and soil tillage indicate that a variation coefficient of crop productivity is high for all crops. Such a situation, in turn, testifies to the significant influence of weather conditions on the

9. The effect of tillage methods on the yield of corn for grain under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure+ NPK	BP	BP+NPK
Average, t/ha	Combined	4.7	5.2	5.4	5.4	5.5
	Shallow	4.3	4.7	5.1	4.9	5.1
	Difference, %	–8	–10	–6	–8	–7
Multiplicity of yield growth compared to the reference area	Combined	–	1.1	1.2	1.2	1.2
	Shallow	–	1.1	1.2	1.1	1.2
Maximum, t/ha	Combined	7.4	9.1	9.9	8.6	8.4
	Shallow	8.1	8.3	9.7	8.7	8.7
	Difference, %	10	–9	–2	2	4
Multiplicity of yield growth compared to the reference area	Combined	–	1.2	1.3	1.2	1.0
	Shallow	–	1.0	1.2	1.1	1.1
Maximum compared to average, multiplicity	Combined	1.6	1.7	1.8	1.6	1.5
	Shallow	1.9	1.8	1.9	1.8	1.7

processes of plant growth and development. Of the investigated crops, the productivity of sugar beets fluctuates to a greater extent (50 %), to a lesser extent – winter wheat after peas and corn for grain (30 %).

Having a rather high instability in hydrothermal conditions over the years, crop rotation productivity fluctuates much less. The variation coefficient for this indicator varies in the range of 15–18 % for fertilization systems, having 13 % for the reference area without fertilizers. This is one of the most important functions of crop rotation – crops response differently to different factors, accordingly, the more crops, the more diverse the system is, which in general significantly increases the sustainability of agriculture.

Therefore, by the general indicator of the average long-term productivity of crop rotation, shallow tillage is inferior to combined tillage by 4–8 %, when having 5 % confidence level (Table 10). That is, the systematic application of manure along with shallow loosening is inferior to the combined cultivation system in terms of the yield of fodder units, which is obviously related to the different quality of plowing the organic fertilizers in the arable layer. The disadvantages of shallow tillage are leveled by the effect of by-products on fertilizer. Optimizing

10. The effect of tillage on crop rotation productivity under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure + NPK	BP	BP + NPK
Average, t/ha	Combined	3.2	3.6	4.2	4.1	4.2
	Shallow	3.0	3.4	4.0	3.9	4.1
	Difference, %	–5	–8	–6	–5	–4
Multiplicity of yield growth compared to the reference area	Combined	–	1.1	1.3	1.3	1.3
	Shallow	–	1.0	1.3	1.2	1.3
Maximum, t/ha	Combined	5.4	6.5	7.2	6.5	6.6
	Shallow	5.5	6.0	6.7	6.6	6.7
	Difference, %	3	–7	–7	1	2
Multiplicity of yield growth compared to the reference area	Combined	–	1.2	1.3	1.2	1.2
	Shallow	–	1.1	1.2	1.2	1.2
Maximum compared to average, multiplicity	Combined	1.7	1.8	1.7	1.6	1.6
	Shallow	1.8	1.8	1.7	1.7	1.7

hydrothermal conditions makes it possible to increase the average long-term crop rotation productivity for all tillage and fertilization variants by 1.6–1.8 times up to the level of 6.0–7.0 tons of fodder units per hectare.

When applying fertilizer systems with manure, the productivity of crop rotation under the traditional combined tillage system is significantly higher by 0.2 tons of fodder units per hectare compared to the variant with shallow loosening. In terms of the profitability of winter wheat grain, it will be about UAH 400 /ha (prices in 2021). At the same time, fuel consumption in the first case will be higher than in the second one by 5 l/ha, which is equivalent to UAH 150/ha at current prices. This indicates that when having livestock specialization with the production of a significant amount of organic fertilizers of animal origin, it is advisable to use a combined system of soil cultivation, for plant-oriented agrarian production to save fuel surface loosening should be used for all crops.

Conclusions. The methods of soil cultivation under different fertilization systems significantly affect some properties of typical black soil. When applying shallow loosening, there is a tendency to increase the density of the subsoil layer, the differentiation of the upper soil layer by the content of nitrogen, phosphorus and potassium, and the growth of humus reserves.

From the studied crops, only winter wheat almost does not respond to the tillage method, in particular after peas, which can be explained by a rather long period from the previous plowing and better conditions of nitrogen nutrition. When applying shallow tillage, row crops reduce their productivity, especially when applying manure for a rather long time. Obviously, this situation can be explained by a decrease in the effectiveness of organic fertilizers during surface distribution without their plowing due to uneven mixing with the arable layer of the soil.

In years of favorable moisture conditions, the negative impact of shallow tillage is leveled by the systematic use of plant waste as a fertilizer when growing sugar beet, corn for grain, peas and barley. This can be explained by the positive effect of mulch, previously left by-products for fertilizer, which decompose faster in the years with favorable hydrothermal conditions, with the release of additional macro- and microelements. Moreover, soybeans always respond well to straw fertilization under both studied tillage systems.

The multiplicity of crop productivity growth when applying different fertilization systems fluctuates greatly by crops in terms of favorable conditions and tillage systems, and by the indicator of crop rotation productivity, it mostly varies in the range from 1.2 to 1.3. The yields of fodder units in favorable years prevail over the ones obtained in average years by 1.7–1.8 times.

When applying fertilization systems with manure, the productivity of the crop rotation under the traditional combined tillage system is significantly higher by 2 centners of fodder units per hectare compared to the variants with shallow loosening. In terms of the profitability of winter wheat grain, it will be about UAH 400/ha. At the same time, fuel consumption in the first case will be higher than in the second one by 5 l/ha, which is equivalent to UAH 150/ha at current prices. This indicates that when having livestock specialization with the production of a significant amount of organic fertilizers of animal origin, it is advisable to use a combined system of soil cultivation, for plant-oriented agrarian production to save fuel surface loosening should be used for all crops.

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ПОВЕРХНЕВИЙ І КОМБІНОВАНИЙ ОБРОБІТОК ЧОРНОЗЕМУ ТИПОВОГО ЗА РІЗНОЇ СПЕЦІАЛІЗАЦІЇ АГРАРНОГО ВИРОБНИЦТВА В ЛІВОБЕРЕЖНОМУ ЛІСОСТЕПУ УКРАЇНИ

Ю.О. Тараріко[1], докт. с.-г. наук, П.В. Писаренко[2], докт. с.-г. наук, Р.В. Сайдак[3], канд. с.-г. наук, Ю.В. Сорока[4], канд. с.-г. наук, Р.В. Олепір[5], канд. с.-г. наук, З.В. Щербина[6], канд. с.-г. наук, О.П. Вдовиченко[7], аспірант

[1] Інститут водних проблем і меліорації НААН, Київ, 03022, Україна;
https://orcid.org/0000-0001-8475-240X; e-mail: urtar@bigmir.net;
[2] Інститут водних проблем і меліорації НААН, Київ, 03022, Україна;
https://orcid.org/0000-0002-2104-2301; e-mail: Pavel_Pisarenko74@ukr.net;
[3] Інститут водних проблем і меліорації НААН, Київ, 03022, Україна;
https://orcid.org/0000-0002-0213-0496; e-mail: saidak_r@ukr.net ;
[4] Інститут водних проблем і меліорації НААН, Київ, 03022, Україна;
https://orcid.org/0000-0001-6228-4131; e-mail: soroka_Yu@bigmir.net ;
[5] Полтавський державний аграрний університет, Полтава, 04047, Україна;
https://orcid.org/0000-0002-0825-7914; e-mail: roman.olepir@pdaa.edu.ua;
[6] Селекційно-генетичний інститут – Національний центр насіннєзнавства та сортовивчення НААН, Одеса, Україна;
https://orcid.org/0000-0002-4630-8372; e-mail: zoyasgi09@ukr.net;
[7] Інститут водних проблем і меліорації НААН, Київ, 03022, Україна;
[8] https://orcid.org/0009-0007-0557-0036; e-mail: alex.ucccf@gmail.com

Анотація. *У статті наведено результати довгострокових експериментальних досліджень впливу різних способів основного обробітку ґрунту на показники родючості ґрунту та продуктивність культур сівозміни на різних фонах удобрення. Польові дослідження проводили протягом 2013–2020 років на землях Полтавської дослідної станції інституту свинарства та агропромислового виробництва НААН. Встановлено, що систематичне застосування органічних і органо-мінеральних систем удобрення супроводжується поліпшенням* *поживного режиму чорнозему типового з диференціацією орного шару за кількістю фосфору і калію за тривалого мінімального розпушення. Відзначається тенденція до зростання щільності у шарах 20–40 і 40–60 см на фоні систематичного мілкого обробітку, де цей показник перевищує верхню риску оптимальних меж 1,0–1,3 г/см³. Фон заорювання гною і мінеральних добрив порівняно з поверхневим розпушуванням дає змогу додатково щорічно секвеструвати 0,3–0,4 т/га вуглецю, що еквівалентно 1,2–1,6 т вуглекислого газу. За середньою багаторічною врожайністю кукурудзи на силос мілке розпушення поступається комбінованому обробітку у середньому на 10 %. Тенденції до зниження середньої багаторічної продуктивності посівів сої, ячменю ярого і гороху при застосуванні мінімального обробітку ґрунту відносно комбінованого проявляються лише на окремих варіантах удобрення. В оптимальних умовах тепло- і вологозабезпечення співвідношення зерна і соломи у сої звужується. На пшениці озимій після гороху відзначається тенденція до переваги мілкого розпушення. Співвідношення зерна до соломи культури у сприятливих умовах значно зростає. Кукурудза краще реагує на комбіновану систему обробітку, яка переважає за виходом зерна мілке розпушення за варіантами удобрення на 6–10 %. В сприятливих умовах співвідношення стебел до зерна істотно зростає, особливо на удобрених фонах. З досліджуваних культур у більшій мірі стосовно особливостей умов року коливається продуктивність буряків цукрових, в меншій мірі – пшениці озимої по гороху і кукурудзи на зерно. За показником середньої багаторічної продуктивності сівозміни мілкий обробіток поступається комбінованому на 4–8 % за рівня достовірності 5 %. За внесення гною доцільно використовувати комбіновану систему обробітку ґрунту, за рослинницької спрямованості аграрного виробництва під усі культури економічно доцільно застосовувати поверхневе розпушення.*

Ключові слова: *обробіток ґрунту, добрива, спеціалізація, аграрне виробництво, сівозміна, вологозабезпечення, урожайність, ефективність*

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FEATURES OF MAIZE GROWING FOR GRAIN IN THE WESTERN FOREST ZONE OF UKRAINE IN THE CONDITIONS OF CURRENT CLIMATE CHANGES

Yu.O. Tarariko[1], Doctor of Agricultural Sciences, M.D. Zosymchuk[2], Ph.D. in Agricultural Sciences, M.H. Stetsiuk[3], O.A. Zosymchuk[4], Ph.D. in Agricultural Sciences, O.A. Danylytskiy[5], Yu.V. Soroka[6], Ph.D. in Agricultural Sciences, O.I. Hulenko[7], Ph.D.

[1] Institute of water Problems and Land Reclamation of NAAS, Kyiv, Ukraine;
https://orcid.org/0000-0001-8475-240X; e-mail: urtar@bigmir.net;
[2] Sarny Research Station of the IWPaLR of NAAS Sarny, Ukraine;
https://orcid.org/0000-0002-7162-8300; e-mail: zosimchykm@gmail.com;
[3] Sarny Research Station of the IWPaLR of NAAS Sarny, Ukraine;
https://orcid.org/0000-0001-6773-2546; e-mail: nick.stetsiuk@gmail.com;
[4] Sarny Research Station of the IWPaLR of NAAS Sarny, Ukraine;
https://orcid.org/ 0000-0001-9656-0181; e-mail: oksana.zosimchyk@gmail.com;
[5] Sarny Research Station of the IWPaLR of NAAS Sarny, Ukraine;
https://orcid.org/0000-0002-0772-0516; e-mail: tsigan770@gmail.com;
[6] Institute of water Problems and Land Reclamation of NAAS, Kyiv, Ukraine;
https://orcid.org/0000-0001-6228-4131; e-mail: soroka_Yu@bigmir.net;
[7] Dnipro State Agrarian and Economic University, Dnipro, Ukraine;
https://orcid.org/0000-0002-1007-5677; e-mail: gulenkoai@gmail.com

Abstract. *Modern climatic changes, namely significant warming in the northern Forest-Steppe and Polissia zones of Ukraine, provide opportunities for the cultivation of a number of grain and leguminous crops (maize for grain, soybeans, sunflower, and others), previously uncharacteristic of this region. Among the above-mentioned crops, corn has the greatest grain yield potential, therefore it is one of the most common crops in world agriculture. If 10–15 years ago corn was not grown for grain in the Polissia zone, then in recent years its sown areas have grown significantly, and the yield in some years is not inferior to the regions of the Forest Steppe and Steppe, which are traditional for this crop. The results of experimental studies of the station showed that under favorable conditions on the most fertile slopes of the drained sod-podzolic soils of the Western Polissia zone, with intensive technologies, it is possible to obtain more than 10–12 t/ha of corn grain.*

The analysis of hydrothermal indicators shows that with the current indicators of heat supply of the growing season in the zone of Western Polissia on mineral soils, it is possible to achieve not only early-ripening, but even medium-early hybrids of corn with FAO up to 280–300. Drained peat soils, due to their high nitrogen content and sufficient amount of moisture, have sufficient potential for obtaining a high yield of corn grain. However, its indicators over the years of research vary greatly and depend to a large extent on the agro-meteorological conditions of the growing season. It has been established that the main limiting factors for achieving a high yield of corn grain on peat soils are less favorable microclimatic features (less amount of active heat, shorter growing season and frost-free period, etc.) compared to adjacent sod-podzolic soils located nearby on dry land. It has been experimentally established that under conditions of minimum duration without a frost period, only the most early-ripening hybrids of corn with FAO up to 220–240 will have time to form a full-fledged crop of grain on drained peat soils in the Western Polissia zone. By choosing late-ripening hybrids, there is a risk of a significant shortfall in the harvest due to the premature termination of vegetation caused by early autumn frosts. It was established that the highest yield of corn per grain, both on sod-podzolic and peat soils, was provided by the organo-mineral fertilization system, which was based on the application of complete mineral fertilizer at the rate of $N_{90}P_{90}K_{90}$ *on turf-podzolic soils and* $N_{35}P_{60}K_{120}$ *on peat soils in combination with phosphorus mobilizing drug Rice Pi. The use of the organo-mineral fertilization system (*$N_{90}P_{90}K_{90}$ *+ phosphorus mobilizing drug Rice Pi) ensured an increase in the yield of corn on sod-podzolic soils by 30.2 ct/ha compared to the basic fertilization system (*$N_{30}P_{30}K_{30}$*). The use of the organo-mineral fertilization system (*$N_{35}P_{60}K_{120}$ *+ phosphorus mobilizing drug Rice Pi) ensured an increase in the yield of corn on peatlands by 56.8 ct/ha compared to the natural background of fertility.*

Key words: *drained lands, corn, varieties and hybrids, zone of Western Polissia, climate changes, fertilization system*

The relevance of research. Corn is one of the most common crops in world agriculture. Its main acreage is concentrated in the USA, Argentina, and Brazil. In the USA, there is a corn belt where it has been grown in monoculture for more than 40 years, and its yield is consistently at least 12–16 t/ha. In addition to the United States, corn monoculture is also practiced in France. Two-field crop rotation is common in the United States, consisting of alternating soybeans and corn. For corn farmers in Canada and the USA, the grain yield standard is 20–25 t/ha [1–3].

The world's highest corn grain yield (total of irrigated and irrigated plantations) is 41.44 t/ha, obtained in 2019 by farmer Dave Hula from Virginia (USA). Hula uses mulching, minimum tillage and irrigation on his farm [1, 4].

On unirrigated fields, the last world record for corn yield was reached in 2002 by Francis Child with a result of 29.73 t/ha. Twenty years later, in 2022, this record was broken by farmer Russell Hendrick from North Carolina (USA). For more than 10 years, Hendrik has been innovating on his 300-hectare farm to improve the properties of his soils. His unirrigated, no-till corn plantation, has reached the 30 t/ha mark. The current yield record is 30.9 t/ha [4]. It is worth noting that the climate of North Carolina is classified as subtropical. The average annual rainfall in this area is about 1100–1300 mm

In Ukraine, irrigation yields 13–15 t/ha of corn grain, in some farms, under favorable conditions, the yield reaches 16 or more t/ha [3–4].

Over the past decade, the corn sown area in Ukraine has increased from 1.9 million hectares in 2007 to 5.3 million hectares in 2021, or more than 2.5 times, and the area of its cultivation has also expanded. It is characteristic that the rate of increase in the average yield of corn per grain in Ukraine is the highest in the world [5]. This is a consequence of the introduction of progressive technologies in its cultivation and the introduction of new highly adapted varieties and hybrids of the world's leading breeding companies.

If 10–15 years ago corn was practically not grown for grain in the Western Polissia zone, recently its sown areas have grown significantly, and the yield in some years is not inferior to the regions of the Forest Steppe and Steppe that are traditional for this crop [2, 4, 6].

There are also examples of corn cultivation in monoculture in Ukraine. In particular, the agricultural company "Zemlya i Volya" in Chernihiv Oblast is a vivid example of successful corn cultivation in monoculture. In recent years, the area under monoculture of corn in this enterprise is about 30.000 hectares, and the yield of grain consistently reaches more than 8–10 t/ha. The technology is based on the plowing of crop residues, the use of trichogram, as well as the introduction of anhydrous ammonia. Periodic analyses of the soil indicate that its quality is gradually increasing due to the constant introduction of organic matter with plant residues. At the same time, there are no outbreaks of diseases or an increase in the number of pests [7].

Studies have proven that the potential yield of corn grain under favorable conditions in the Western Polissia zone can be more than 11–12 or more t/ha, however, to obtain such a yield, many factors and technological nuances specific to this zone should be taken into account [2, 3, 8, 9, 10].

Analysis of recent research and publications. A significant amount of research on the selection of the most highly productive and adapted corn hybrids for the Western Polissia zone, including on drained lands, is being conducted by Zakhidagroprom LLC, which in 2019 launched the Agrarian Polygon project in the village of Yarynivka, located in the north of the Rivne region. The data obtained at the Agrarian Polygon show that the yield of corn grain in the Western Polissia zone significantly depends on the cultivated hybrid, its maturity group and the weather conditions of a particular year. Thus, in 2020, certain hybrids of corn under production conditions ensured a grain yield of more than 14–15 t/ha. It was also established that the difference in productivity between individual hybrids can differ quite significantly [6].

Researches of the Polyssia Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine have established that among crops, corn has a high yield potential on sod-podzolic soils. Thus, in the conditions of drained soddy-podzolic soils, the highest yield of grain (6.05 t), feed (6.56 t) and feed protein units (5.66) per 1 ha of area was obtained in a three-field crop rotation with 66.6 % corn per combination by-products with an increased rate of mineral fertilizers ($N_{63}P_{85}K_{90}$).

A decrease in the share of corn to 33.3 % in a three-field crop rotation and to 25 % in a four-field crop rotation under a similar fertilization system led to a decrease in their productivity – to 4.52 and 4.23 tons of grain or 5.44 and 4.52 tons of fodder units, in accordance. Crop rotation without corn reduced harvest by an average of 50 % [11].

It should be noted that most of the studies on the cultivation of corn for grain in the Polissia zone were conducted on sod-podzolic soils and their variations. Regarding the cultivation of corn for grain on drained peat soils, this issue has not been sufficiently studied until recently, as it was grown here mainly as a fodder crop to obtain high-quality silage.

Peat soils naturally have a high supply of nitrogen [9, 10], therefore, in the conditions of a significant increase in the price of nitrogen fertilizers, they can be considered as a significant reserve for expanding the area of corn for grain in the Polissia zone.

The research of the Sarnenska Research Station in recent years shows that with proper phosphorus-potassium nutrition and the correct selection of hybrids on peat soils, it is possible to obtain a high yield of corn grain. However, on peat soils, there are many limiting factors and nuances of technology, and not taking them into account makes it impossible to fully realize the potential of this crop. In particular, peat soils, compared to adjacent mineral soils located on dry land, have specific water-physical and microclimatic features. Here, the vegetation and frost-free period is much shorter, which greatly complicates the corn's cultivation [13].

Therefore, the issue of growing corn for grain in the Western Polissia zone has not been sufficiently studied until recently, especially on peat soils, as well as the selection of varieties and hybrids according to maturity groups, the establishment of optimal sowing dates, the effectiveness of fertilization and the use of plant growth regulators, etc.

The aim of the research. The purpose of the research is to carry out an agroclimatic substantiation of the possibility and feasibility of growing corn for grain on the drained lands of the Western Polissia zone.

Research materials and methods. In 2019, the Sarnenska Research Station of the National Academy of Agrarian Sciences of Ukraine began studying the possibility of growing corn for grain on drained sod-podzolic and peat soils.

Research methodology. Research on the selection of the most productive and adapted corn hybrids for grain is carried out on the drained peat-boggy massif of the "Chemerne" Sarnenska experimental station (Rivne region).

In terms of morphological characteristics, botanical composition, water-physical and agrochemical properties, this massif is typical for the Western Polissia – a deep, medium-ash non-flooding hypnotic-sedge swamp of the lowland type.

In addition to peat soils, the land use of the station includes turf-podzolic soils. These soil types are the most common in the Western Polissia zone, so the data obtained here are representative for the entire region.

The soils of the experimental sites (peat and sod-podzolic soils) have a slightly acidic reaction of the soil environment (pH_{salt} 4.6–5.0).

Research results. When planning the cultivation of corn in the Western Polissia zone, it should be remembered that there are many limiting factors and nuances of the technology, without taking into account which it is impossible to fully reveal its potential. These main limiting factors include the low natural fertility of most soils in this zone, high acidity, and high variegation of the soil cover, and corn is one of the most demanding crops in terms of the level of fertility and fertilization of crops. In addition, one of the main conditions for obtaining a high grain yield of this crop is a sufficient amount of moisture in the soil [3, 10, 12].

Thermal resources are also more limited in the Polissia zone compared to the Forest-Steppe and Steppe zones (shorter growing season, lower sum of active temperatures, etc.). In addition, it is necessary to approach the timing of sowing and the choice of maturity group of hybrids very carefully, because in Polissia there is always a threat of late spring frosts, which can be observed even at the end of May, and the first autumn frosts can come already at the beginning of September, causing significant damage to crops. However, the western and northern regions of Ukraine are a territory where there is still enough moisture, without which it is problematic to achieve a good corn harvest [11–14].

The main indicators that characterize the heat supply of plants during the growing season are the average monthly air temperatures and their anomalies, the dates of the beginning and end of different temperature periods, in particular, the growing season (warm) and the period of active vegetation, the sum of active and effective temperatures, and others [15].

The dates of stable transition of the average daily air temperature through 0, 5, 10, and 15 °C and the duration of periods with temperatures above these limits are used to determine the duration of vegetation of cold-resistant (period with a temperature above 5 °C) and heat-loving (above 10 °C) crops, during the period of their intensive growth (over 15 °C), when planning the dates of the start of fieldwork in the spring (dates of transition through 5 °C) and their termination (transition through 0 °C) in autumn, etc. (Table 1).

Analysis of the dates of stable temperature transition confirms the tendency of recent decades towards an earlier start of the growing season (on average 10 days earlier than normal) and a later end, which ultimately results in an increase in the duration of the growing season by an average of 11 days. Over the years of research, its duration ranged from 186 to 248 days with an average

1. Dates of stable transition of temperature through 0, 5, 10, 15 °C and the duration of the corresponding periods on the drained peat-boggy massif "Chemerne" (Rivne region), average for 2007–2021

Value	The dates of the temperature transition through certain limits and the duration of the corresponding periods											
	> 0°	< 0°	days	> 5°	< 5°	days	> 10°	< 10°	days	> 15°	< 15°	days
$D_{average}$	24.02	5.12	284	25.03	30.10	217	22.04	3.10	163	12.05	7.09	116
D_{min}	26.01	9.11	254	14.03	6.10	186	4.04	24.09	128	27.04	24.08	100
D_{max}	30.03	31.11	331	11.04	25.11	248	30.04	23.10	188	7.06	18.09	141

of 217 days. The duration of the active growing season (with temperatures > 10 °C) exceeded the norm by an average of 5 days, and the intensive growing season (>15 °C) by 10 days. In most cases, the growing season on the station's peat swamp massif began in the III-rd ten days of March, and the active growing season began in the III-rd ten days of April.

It should be noted that according to the data of Belarusian scientists (Republican Center of Hydrometeorology) in the territory of Belarusian Polissia, since 1989, an abnormally early steady transition of the air temperature past 0 °C in spring has also been registered. On average, from 1989–2015, the transition of air temperature through 0 °C in spring occurs 8–13 days earlier than the multi-year dates. The transition of air temperature by 5 and 10 °C in spring also occurs earlier than multi-year dates by 7–10 and 2–7 days, respectively [16, 17]. These data are fully consistent with the data of our weather station in almost all key indicators.

When planning the cultivation of corn for grain in the Western Polissia zone, it should be remembered that this is a heat-loving crop, so the selection of the maturity group of hybrids should be carefully considered, taking into account the limited thermal resources of this soil-climatic zone [3, 9, 10].

Recently, breeders have created many new precocious corn hybrids specifically for growing in conditions of limited thermal resources, which significantly expands the window of opportunity for growing corn for grain [3].

It is known that the sums of active temperatures during the period of active vegetation in the Polissia zone in different years range from 2140 to 2600 °C. The sum of active temperatures at which early-ripening hybrids reach is 2100–2200 °C, mid-early and mid-ripening – 2400–2600 °C, and late-ripening – 2800–3200 °C. There are several options for dividing hybrids by maturity groups. One of them is given in the Table. 2.

However, during the vegetation period, crops of heat-loving crops use less active heat than the amount that enters the areas of the Western Polissia zone. This is because the growing season is limited by spring and autumn frosts, as well as the late sowing of corn. According to the data of scientific institutions, the frequency of reaching different maturity groups of corn hybrids with different heat supplies is characterized by the following data, fig. 1.

Research by scientific institutions has established that in the Polissya zone, stable growth of early hybrids is possible only with the sum of active temperatures above 10°C – 2800°C. These materials indicate that at an active heat of 2400°C, early-ripening varieties of corn reach 60 %, medium-ripening – 50 %, medium-early – 30 %, and medium-late – 10 %. Full maturation of medium-early and

2. The need of different groups of varieties and hybrids of corn in warmth during the growing season

Ripeness group	The sum of the active temperatures, above 10 °C	FAO number	Vegetation period, days**	Number of leaves
Very early ripening	2100	100–149	80–90	10–12
Early ripening	2200	150–199	90–100	12–14
Mid-morning	2400	200–299	100–115	14–16
Medium ripe	2600	300–399	115–120	17–18
Mid-late	2800	400–499	120–130	19–20
Late ripening	2900–3000	500–599	135–140	21–23
Very late ripening	> 3000	>600	>140	>23

* the temperature exceeding 10 °C is summed

** from emergence to maturity.

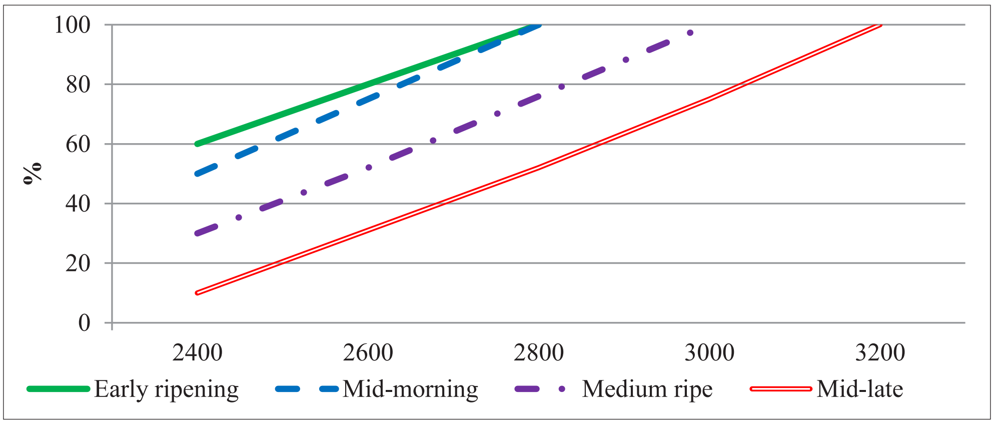

Fig. 1. The probability of reaching corn hybrids of different maturity groups at different sums of active temperatures

early-ripening hybrids occurs at the sum of active temperatures – 2800 °C, medium-late – 3200 °C and medium-ripening – 3000 °C.

Based on the above data, when choosing corn hybrids by maturity groups, one should be guided by the recommendations for the zonal placement of corn crops depending on the FAO index [18], which is shown in Fig. 2.

It should be noted that since 2000, both the duration of the growing season and its heat supply have been increasing most intensively. Since 2010, the sum of active temperatures during the period of active vegetation in most years has consistently exceeded 2600 °C, while 25–30 years ago this indicator reached this mark only in some years (Fig. 3).

The dynamics of the sum of active temperatures (>10 °C) over the last 10 years exceeded 2600 ºC in 8 years. Based on the above data, it can be stated that on the sod-podzolic soils of the Western Polissia zone, it is possible to grow not only early-ripening, but also mid-early hybrids of corn with FAO 250–260. However, in years with minimal amounts of active heat, it is sufficient only to reach the earliest varieties and hybrids of corn.

The hydrothermal conditions of the period of active vegetation (PAV) on the drained peat-boggy massif of the Sarnenska research station for the last 5 years are shown in the table 3.

The coefficient of significance of deviations (anomalies) of the weather indicator of a specific year from long-term average annual

Ki ≤ 1 agro-climatic characteristics of the year are close to usual (long-term average annual)

1 < Ki ≤ 2 agroclimatic characteristics of the year are significantly different from long-term average annual – *italics.*

Ki > 2 agroclimatic characteristics this year are approaching rare (exceptional, extreme) – **bold.**

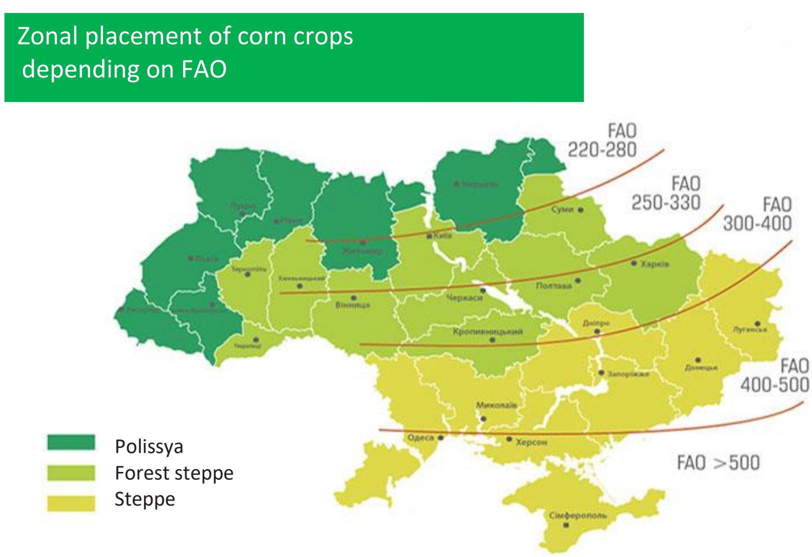

Fig. 2. Recommended zonal placement of corn crops depending on the FAO indicator

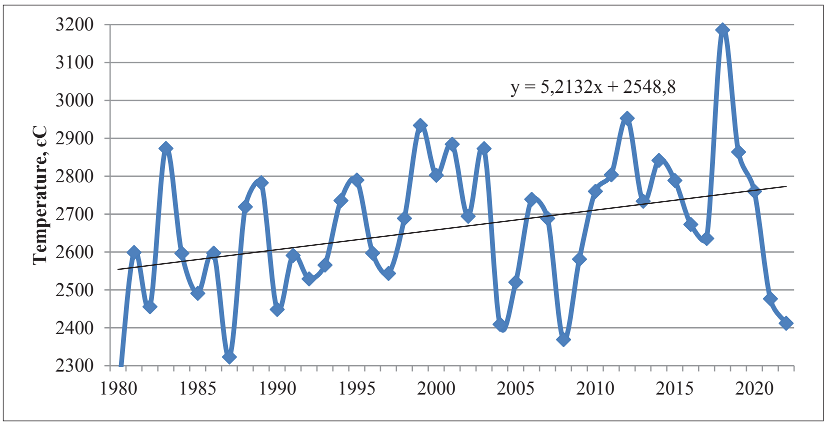

Fig. 3. Dynamics of the sum of active temperatures above 10 °C for the peat-boggy massif "Chemerne" in 1980–2022

3. Hydrothermal conditions of the period of active vegetation (PAV) on the drained peat-boggy massif of the Sarnenska research station

Year	Period of active vegetation (PAV)			The average tempera-ture of PAV, °C	The sum of active tempera-tures during PAV, °C	Amount of precipitation, mm	HTC
	start (spring)	finish (autumn)	duration				
2018	**4.04**	*19.10*	**198**	16.9	**3186**	247.8	*0,78*
2019	23.04	**28.10**	*188*	16.2	*2864*	323,1	1,13
2020	28.04	*16.10*	171	16.7	*2760*	341,9	1,24
2021	30.04	*18.09*	*141*	*18.0*	2477	228,2	0,92
2022	24.04	20.09	149	16.8	2412	*200,5*	*0,83*
Average	**22.04**	**08.10**	169	16.9	2740	268,3	0,98
Minimum	04.04	18.09	141	16.2	2412	200,5	0,78
Maximum	30.04	28.10	198	18.0	3186	341,9	1,24
The amplitude, days	26	40	57	1.8	774	141,4	0,46
long-term average annual	26.04	30.09	158	16.3	2498	302,2	1,23
Δ aver. to long-term average annual	−4	+8	+11	+0,6	+243	−33,9	−0,25

The duration of the period of active vegetation in 2018 was 198 days, and this is the second indicator for the entire time of systematic weather observations at the station (78 years, in 1967 it was 214 days). Reliability of indicator P = 2.2 %, repeatability N= once every 46 years.

The sum of active temperatures according to PAW in 2018 was 3186ºC, which is the highest indicator during systematic weather observations at the station (reliability of indicator P = 0.9 %, repeatability N = 111 years, i.e. 1 time in 111 years)

In general, it should be noted that the hydrothermal conditions during the period of active vegetation in the peat-boggy massif of the Sarnenska experimental station were characterized by high variability over the years of research.

One of the dangerous meteorological phenomena that complicates the cultivation of corn for grain in the Polissia zone is a short frost-free period. The dates of late spring and early autumn frosts over the past 5 years in the "Chemerne" peat-boggy massif (Rivne region) are given in the Table. 4.

According to the weather station of the Sarnenska research station, which is located directly on the peat-boggy massif, in some years the last spring frosts in the Western Polissia zone

4. The duration of the frost-free period on the drained peat-boggy massif of the Sarnenskф Research Station over the past 5 years

Year	Date of last spring frost in the air	Date of first autumn frost in the air	The duration of the frost-free period
2018	28.04	26.09	150
2019	09.05	19.09	132
2020	21.05	20.09	121
2021	09.05	05.09	118
2022	24.05	01.09	99
2023	14.05	8.09	117
Long-term average annual	**08.05**	**23.09**	137

can be observed even at the end of May, and the first autumn frosts can be observed already in the first days of September, as it was in 2021–2022. The average long-term duration of the frost-free period on the "Chemerne" peat-boggy massif is 137 days. However, there are years with an abnormally short frost-free period. So, for example, in 2022, the frost-free period was only 99 days.

A valuable biological feature of corn is that until the 5–6 leaf phase, its growth point is in the soil, which allows the crops to withstand late spring frosts, which in the Polissia zone can be observed throughout May. According to long-term observations of station scientists, late spring frosts in very rare cases can destroy corn crops. Usually, only the above-ground part of the plant is damaged, while the growing point of corn remains undamaged in 90 % of cases. A valuable biological feature of corn is that up to the 6–7th leaf, the growth point of corn is still in the soil, therefore, even if the above-ground part is severely damaged by frost, its root system continues to develop during this period and the regrowth of the crop occurs with an already well-developed root system [3, 4].

In the experiments of the station, which were carried out on drained peatlands, cases were repeatedly noted when corn seedlings completely died due to the harmful effects of frost, but the growth point in the soil remained intact, and after 8–10 days, regrowth of corn plants took place. In addition, reseeded plots of corn did not provide higher grain yields than those that were affected by frost and re-grown again without reseeding.

The station's research shows that early autumn frosts are extremely dangerous for corn, as adult corn plants die already at a temperature of –1^{o}C. In some years, the first autumn frosts in the Polissia zone can be observed in the first decade of September (especially on peat soils and low relief elements). Therefore, only the most early-ripening hybrids of corn with FAO up to 200–220 will have time to form a full-grain crop. By choosing late-ripening hybrids, there is a risk of a significant shortfall in the harvest or even its complete loss due to the premature termination of vegetation caused by frost.

Changes in the temperature regime of the soil. Climate changes observed in the last decade create new conditions for growing crops. Knowledge of changes in the parameters of the hydrothermal regime of the soil in the context of climatic changes and, accordingly, clarification of the terms of sowing of the main crops are especially relevant. The key indicator for determining when to sow corn is the temperature of the 0–10 cm soil layer. The optimal indicator for its sowing is the soil temperature in the 0–10 cm layer – 10 °C. According to the archive data of the station, 50–60 years ago, such soil temperature on the peat soils of the station occurred at the beginning of the second 10 ten days of May [19]. Based on the data of the temperature regime of the soil of the last 5 years (data of the meteorological station of the station), the temperature of the soil in the layer of 0–10 cm on peat soils reaches 10 °C at the end of the third ten-day period of April, which is optimal for sowing corn for grain [20]. This indicates the expediency of shifting the terms of sowing corn for grain in the Western Polissia zone to earlier – by 8–12 days.

The research conducted in recent years at the Agrarian Polygon of "Zakhidagroprom" LLC shows that due to modern climate changes, namely the significant warming of the climate, it is possible to grow corn for grain in the Western Polissia zone. In some years, even medium-ripe corn hybrids with FAO 310–330 had time to form physiologically ripe grain [6].

In addition, in recent decades, breeders have created many early-ripening and cold-resistant corn hybrids, suitable for growing in conditions of limited thermal resources.

So, summarizing the above, corn should be sown in the Western Polissia zone as early as possible, as soon as the temperature in the 0–10 cm soil layer reaches 8–10 °C, which mostly falls at the end of the third ten-day period of April. If cold-resistant hybrids are used, sowing can be started from April 22–23, when the temperature in the 0–10 cm soil layer reaches 8 °C. In the spring, mineral soils warm up faster than peat soils, so corn sowing can be started here a few days earlier.

Early periods of corn sowing contribute to the effective use of winter moisture reserves, and the flowering of plants does not fall on a critical temperature period. Late sowing times slow down the ripening period by 17–20 days, while the moisture content of the grain is quite often 30 % or more, and its drying to basic indicators requires almost half of the energy resources from the total amount of them for cultivation [3, 4, 10, 11, 21].

The research of the station shows that the relative humidity of the air on peat soils is 10–12 % higher than on the adjacent terrestrial soils, which is associated with a significant saturation of the ground air layer with water vapor due to the evaporation of the peat soil. Therefore, when growing on peat soils, corn hybrids with the highest moisture yield should be chosen.

The yield of corn on drained sod-podzolic and peat soils of the Sarnenska Research Station of the IWPaLR of NAAS of Ukraine in the cross-section of hybrids of different maturity groups is shown in the table. 5–6.

As the conducted studies showed, during 2019–2021, the highest grain yield indicators had the Dekalb company's hybrids – DK 315 and DKS 3969 – 10.30 and 9.43 t/ha, respectively. A high yield rate was also noted for the Pandoras hybrid of Syngenta selection – 9.27 t/ha. Hybrids of domestic selection – Yarovets 234 MV and Orlyk were inferior to hybrids of foreign selection in terms of grain yield. Their average yield over 3 years was 7.68 and 7.50 t/ha.

Drained peat soils have a high nitrogen content and sufficient moisture, making them well-suited for growing corn. However, there are several limiting factors and nuances of technology, which have to be taken into account to achieve a high yield of corn grain on peat soils. The main limiting factor in achieving a high corn grain yield on peat soils is less favorable microclimatic conditions (less amount of active heat, shorter growing season and frost-free period, etc.) than on nearby land soils. Therefore, the yield of corn on peat soils varies significantly over the years of research and largely depends on the agrometeorological conditions of a particular year. The most significant influence is exerted by the duration of the frost-free period of a particular year and especially the timing of the onset of the first autumn frosts, most of which cause premature termination of the growing season and a shortage of crops due to insufficient grain filling. Comparing the data in tables 4 and 5, it can be seen that with a reduction in the duration of the frost-free period, there is a significant decrease in the yield of corn grain.

When growing corn for grain in the Western Polissia zone, one of the important elements of growing technology is the sowing time. Their effect on corn yield is reflected by the research results obtained in field experiments in 2022 (Table 6).

The data in Table 6 confirm the critical importance of observing the optimal corn sowing dates in the Western Polissia zone. A 16-day delay in sowing led to a decrease in corn yield to 30–35 %. Corn hybrids sown later did not have time to form a well-filled grain before the onset of the first autumn frosts, which in 2022 occurred abnormally early – in the first ten days of September.

5. The yield of corn hybrids of different maturity groups when grown on drained peat soils, (application of $N_{35}P_{60}K_{90}$)

Hybrids	**FAO number**	**Productivity at 14 % basic humidity, t/ha**			**Average**
		2019	**2020**	**2021**	
ДК 315 (Dekalb)	310	10.67	11.06	9.17	10,30
ДКS 3969 (Dekalb)	310	9.79	10.29	8.20	9,43
Pandoras (Syngenta)	250	10.01	10.22	7.57	9,27
Kan'yons (KWS)	230	7.95	8.96	6.79	7,90
Yarovets 234 MV (NAAS)	240	8.01	8.54	6.48	7,68
Orlyk (NAAS)	280	8.12	7.98	6.39	7,50
$LSD_{0,5}$ t/ha		0,441	0.389	0.402	

6. The yield of corn hybrids on sod-podzolic light loamy soils of the Sarnenska Research Station, 2022

Sowing date	Hybrid	Originator	FAO number	Productivity, t/ha	
				sod-podzolic soils	peat soils
9. 05.2022	P 8521	Pioneer USA	220	9.33	8.22
	P 7948	Pioneer USA	210	10.30	8.39
	ДКS 3730	Dekalb USA	280	12.48	8.44
	P 9234	Pioneer USA	320	12.81	6.73
	P8834	Pioneer США	280	13.45	7.47
	P 8812	Pioneer USA	290	13.64	7.01
	ДК 315	Dekalb USA	310	14.88	9.24
The average of 7 hybrids				**12.41**	**7.93**
27. 05.2022	P 7043	Pioneer USA	160	7.61	6.26
	ДКS 3441	Dekalb USA	220	8.37	5.86
	Marimba	Syngenta Switzerland	240	8.25	4.44
	Fortago	Syngenta Switzerland	260	8.04	5.21
	Foton	Syngenta Switzerland	260	9.55	4.55
The average of 5 hybrids				8.36	5.26

Fertilization system ($N_{90}P_{90}K_{90}$ + phosphorus-mobilizing agent Rice Pi turf-podzolic soils; and $N_{60}P_{60}K_{120}$ + phosphorus-mobilizing agent Rice Pi – peat soils)

In the technology of growing corn, the fertilization system is important, because it is one of the most demanding crops in terms of soil fertility and the level of mineral nutrition [1, 3, 12].

The results of studies on determining the effect of fertilization systems on the yield of corn on sod-podzolic and peat soils are shown in the Table 7.

The analysis of corn yield shows that depending on the fertilization system, the grain yield on peat soils was in the range of 3.66–9.34 t/ha and 10.91–13.93 t/ha on sod-podzolic light loamy soils. The significantly lower yield of corn per

7. The influence of fertilization systems on the yield of corn hybrid DK 315 (Dekalb) on the drained lands of the Sarnenska experimental station of the IWPaLR of NAAS of Ukraine, 2021–2023

Fertilizations options and biopreparations	Productivity, t/ha	± to control		± to standart	
		t/ha	%	t/ha	%
Sod-podzolic light loamy soils					
$N_{30}P_{30}K_{30}$ (control)	10.91	–	–	–	–
PPP (Biosil + Stimpo + Regoplant)	12.19	1.28	1.17	–	–
Phosphorus-mobilizing agent Rice Pi	12.67	1.76	1.61	–	–
$N_{90}P_{90}K_{90}$ (standart)	13.03	2.12	1.94	–	–
$N_{90}P_{90}K_{90}$ + PPP (Biosil + Stimpo + Regoplant)	13.56	2.65	2.43	0.53	0.41
$N_{90}P_{90}K_{90}$ + Phosphorus-mobilizing agent Rice Pi	13.93	3.02	2.77	0.90	0.69
$LSD_{0.5,\ t}$/ha	0.409				
Peat soils					
Without fertilization (control)	3.66	–	–	–	–
PPP (Biosil + Stimpo + Regoplant)	4.83	1.17	3.20	–	–
Phosphorus-mobilizing agent Rice Pi	5.25	1.59	4.34	–	–
$N_{35}P_{60}K_{120}$ (standart)	8.08	4.42	12.08	–	–
$N_{35}P_{60}K_{120}$ + PPP (Biosil + Stimpo + Regoplant)	8.75	5.09	13.91	0.67	0.83
$N_{35}P_{60}K_{120}$ + Phosphorus-mobilizing agent Rice Pi	9.34	5.68	15.52	1.26	1.56
LSD $_{0.5,\ t}$/ha	0.334				

grain on peat soils is explained by the fact that the corn vegetation here for 2 years in a row (2021–2022) was stopped in the first ten days of September due to abnormally early autumn frosts, which did not allow the full potential of the studied hybrids to be realized.

During this period, no frost was observed on turf-podzolic soils located nearby on dry land, which allowed the full potential of the studied corn hybrids to be realized.

Regarding the effectiveness of the researched fertilization systems, the use of plant growth regulators Biosil, Stimpo, and Regoplant ensured an increase in the yield of corn per grain on sod-podzolic soils by 1.28 t/ha or by 11.7 % and on peat soils by 1.17 t/ha ha or 32.0 %. The use of the phosphorus-mobilizing drug Rice Pi increased the yield of corn on sod-podzolic soils by 1.76 t/ha or 16.1 % and on peat soils by 1.59 t/ha or 43.4 %.

Application of the mineral fertilization system on sod-podzolic soils ensured an increase in yield by 2.12 t/ha or 19.4 % and on peat soils by 4.42 t/ha or 120.8 %.

The use of a mineral fertilizer system in combination with plant growth regulators Biosil and Stimpo ensured an increase in the yield of corn on sod-podzolic soils by 2.65 t/ha or by 24.3 % and on peat soils by 5.09 t/ha or 139.1 %. The combination of the mineral fertilizer system with the phosphorus-mobilizing agent Rice Pi ensured an increase in the yield of corn on sod-podzolic soils by 3.02 t/ha or by 27.7 % and on peat soils by 5.68 t/ha or 155.2 %.

Apart from small-scale experiments, in 2019–2021 the Sarnen research station carried out research on the adaptation and introduction of new varieties and hybrids of crops and their cultivation technologies in modern soil and climatic conditions for the maximum realization of the agricultural resource potential of the reclaimed agro-landscapes of Western Polissia.

During 2019–2021, researches were carried out with corn on 3 types of drained soils (organogenic, mineral, and organomineral). Organogenic soils are represented by thick peat soils, mineral soils are soddy-podzolic sandy loam soils, and organic-mineral soils are soddy-podzolic peat soils.

The total area of experimental plots in 2019–2021 on soddy-podzolic sandy loam soils was 89.0 hectares, peat soils – 292.0 hectares, and organomineral soils – 19.5 hectares. For the research, a mid-season corn hybrid DK 315 of the Dekalb brand from FAO 310 was chosen.

The fertilization system for mineral and organomineral soils consisted of applying complete mineral fertilizer at the rate of $N_{100}P_{60}K_{60}$. Mineral fertilizers were applied in the form of nitroammophoska NPK 16:16:16 and carbamide.

On peat soils, the fertilization system consisted in the application of complete mineral fertilizer at the rate of $N_{18}P_{60}K_{90}$ + application of 2 t/ha of dolomite flour. Mineral fertilizers were applied in the form of polyphoska 6–300 kg in physical weight. Additionally, 2 c/ha of dolomite flour was applied.

In addition, to reduce the acidity of peat soils, liming was carried out at the rate of 2 t/ha of $CaCO_3$.

In general, during 2019–2021, the yield of corn per grain was as follows (Fig. 4):

2019 on turf-podzolic soils 7.75 t/ha, on peat – 8.81 t/ha, on organic-mineral – 10.36 t/ha.

2020 on sod-podzolic soils – 11.51 t/ha, on peat – 11.05 t/ha, on organo-mineral – 13.67 t/ha.

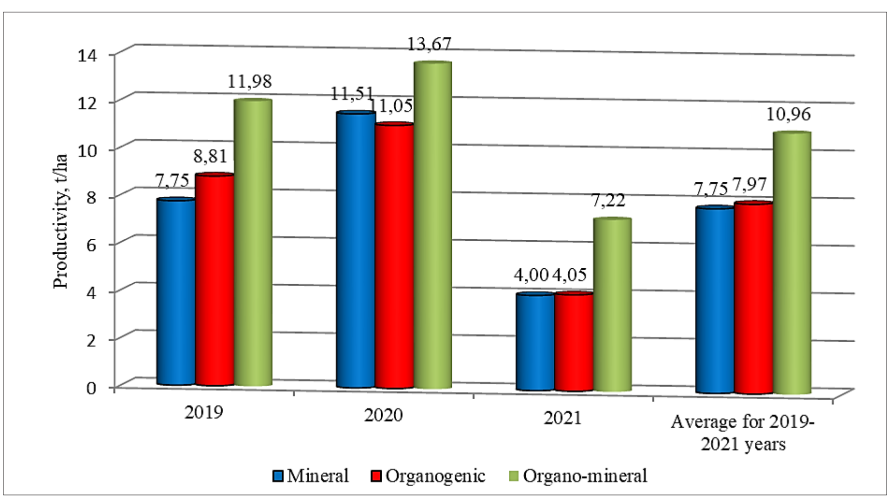

Fig. 4. Maize yield of the DK 315 hybrid on different types of drained soils of the Sarny Research Station

2021 on sod-podzolic soils – 4.00 t/ha, on peat – 4.04 t/ha, on organo-mineral – 7.22 t/ha.

In the conditions of 2021, the lowest yield of corn grain was obtained in 3 years. Such a decline in productivity is explained by a complex of negative factors that developed in the conditions of 2021, namely:

– in July, there was a long-term air drought, which led to poor pollination of corn heads, which resulted in a significant shortfall in harvest compared to previous years;

– premature cessation of vegetation caused by abnormally early autumn frosts noted in the first ten days of September;

– abnormally cold April, due to which corn sowing in 2021 was carried out 12–14 days later compared to the previous 2019–2020 years.

The above complex of factors caused a sharp decrease in the yield of corn in 2021 compared to the previous 2 years.

On average, over the 3-year cycle of research, the yield of corn per grain on sod-podzolic soils was 7.75 t/ha, on peat soils – 7.97 t/ha, on organo-mineral soils – 10.96 t/ha. It should be noted that the highest rates of corn yield per grain were obtained when grown specifically on organo-mineral soils (peatted sod-podzolic soils bordering lowland peat soils).

In general, the results of field studies 2019–2021 indicate a significant impact of weather conditions during the active growing season of a particular year on corn yield. Analyzing the data in Table 3, it was established that the most favorable hydrothermal conditions for growing corn for grain were in 2019–2020, when the HTC was 1.13 and 1.24, respectively, and the duration of the period of active vegetation was 188 and 171 days, respectively. The amount of precipitation in these years was 323 and 342 mm, which is close to the long-term norm. The analysis of the yield of corn per grain shows that it was in 2019–2020 that the highest yield indicators were obtained in the experiments, regardless of the type of soil.

Also, studies have shown that when planning to grow corn in the Western Polissia zone, especially on peat soils, it is necessary to observe the earliest possible sowing dates, as well as to choose early-ripening corn hybrids with FAO up to 220–240, so that before the first autumn frosts, the plants have time to form a well-filled and physiologically ripe grain.

Conclusions. The analysis of the main hydrothermal indicators shows that with the current indicators of the heat supply of the growing season in the zone of the Western Polissia on sod-podzolic soils, it is possible to achieve not only early-ripening but even mid-early hybrids of corn with FAO up to 280–300. At the same time, when growing on peat soils in years with minimal amounts of active heat, it is enough only to reach the most early-ripening hybrids of corn with FAO up to 220–240. By choosing late-ripening hybrids, there is a risk of a significant crop shortage.

The results of the station's experimental research showed that under favorable conditions on the most fertile slopes of drained sod-podzolic soils of the Western Polissia zone, with intensive technologies, it is possible to obtain more than 12.0 t/ha of corn grain.

Drained peat soils, due to their high nitrogen content and sufficient amount of moisture, have sufficient potential for obtaining a high yield of corn grain. However, its indicators by research years vary greatly and largely depend on the agrometeorological conditions of the growing season of a particular year.

It was established that the main limiting factors for achieving a high yield of corn grain on peat soils are less favorable microclimatic features (less active heat, shorter growing season and frost-free period, etc.). It was found that the highest yield of corn per grain both on sod-podzolic and peat soils was provided by the organo-mineral fertilization system, which was based on the application of complete mineral fertilizer in the norm of $N_{90}P_{90}K_{90}$ on turf-podzolic soils and $N_{35}P_{60}K_{120}$ on peat soils in combination with phosphorus-mobilizing agent Rice Pi.

The application of an organomineral fertilization system ($N_{90}P_{90}K_{90}$ + phosphorus-mobilizing drug Rice Pi) increased the yield of corn on sod-podzolic soils by 3.02 t/ha compared to the basic fertilizer system ($N_{30}P_{30}K_{30}$). The use of an organo-mineral fertilization system ($N_{35}P_{60}K_{120}$+ phosphorus-mobilizing agent Rice Pi) ensured an increase in the yield of corn on peat soils by 5.68 t/ha compared to the natural background of fertility.

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УДК 633.34:631.4

ОСОБЛИВОСТІ ВИРОЩУВАННЯ КУКУРУДЗИ НА ЗЕРНО НА ОСУШУВАНИХ ЗЕМЛЯХ У ЗОНІ ЗАХІДНОГО ПОЛІССЯ УКРАЇНИ В УМОВАХ СУЧАСНИХ КЛІМАТИЧНИХ ЗМІН

Ю.О. Тараріко[1] докт. с.-г. наук, М.Д. Зосимчук[2], канд. с.-г. наук, М.Г. Стецюк[3], О.А. Зосимчук[4], канд. с.-г. наук, О.А. Данилицький[5], Ю.В. Сорока[6], канд. с.-г. наук, О.І. Гуленко[7], докт. філософії

[1] Інститут водних проблем і меліорації НААН, Київ, Україна;
https://orcid.org/0000-0001-8475-240X; e-mail: urtar@bigmir.net;
[2] Сарненська дослідна станція ІВПіМ НААН, Сарни, Україна;
https://orcid.org/0000-0002-7162-8300; e-mail: zosimchykm@gmail.com;
[3] Сарненська дослідна станція ІВПіМ НААН, Сарни, Україна;
https://orcid.org/0000-0001-6773-2546; e-mail: nick.stetsiuk@gmail.com;
[4] Сарненська дослідна станція ІВПіМ НААН, Сарни, Україна;
https://orcid.org/ 0000-0001-9656-0181; e-mail: oksana.zosimchyk@gmail.com;
[5] Сарненська дослідна станція ІВПіМ НААН, Сарни, Україна;
https://orcid.org/0000-0002-0772-0516; e-mail: tsigan770@gmail.com;
[6] Інститут водних проблем і меліорації НААН, Київ, Україна;
https://orcid.org/0000-0001-6228-4131; e-mail: soroka_Yu@bigmir.net;
[7] Дніпровський державний аграрно-економічний університет, Дніпро, Україна;
https://orcid.org/0000-0002-1007-5677; e-mail: gulenkoai@gmail.com

Анотація. *Сучасні кліматичні зміни, а саме суттєве потепління, в зонах північного Лісостепу та Полісся України сприяє вирощуванню низки зернових та зернобобових культур (кукурудза на зерно, соя, соняшник та ін), раніше непритаманних для цього регіону. Серед вищевказаних культур кукурудза володіє найбільшим потенціалом урожайності зерна, тому є однією з найбільш поширених культур у світовому землеробстві. Якщо ще 10–15 років тому вирощування кукурудзи на зерно в зоні Полісся не практикували, то останнім часом її посівні площі істотно виросли, а врожайність не поступається традиційним для цієї культури регіонам Лісостепу та Степу. Результати експериментальних досліджень Сарненської дослідної станції показали, що в сприятливих умовах на найродючіших відмінах осушуваних дерново-підзолистих ґрунтів зони Західного Полісся при інтенсивних технологіях можна одержати понад 10–12 т/га зерна кукурудзи. Аналіз гідротермічних показників свідчить, що при нинішніх показниках теплозабезпеченості вегетаційного періоду в зоні Західного Полісся на мінеральних ґрунтах можливе достигання не тільки ранньостиглих, а навіть середньоранніх гібридів кукурудзи з ФАО до 280–300. Осушувані торфові ґрунти завдяки високому вмісту азоту та достатній кількості вологи володіють потрібним потенціалом для одержання високої урожайності зерна кукурудзи. Однак її показники по роках досліджень сильно варіюють і значною мірою залежать від агрометеорологічних умов вегетаційного періоду конкретного року. Встановлено, що основними обмежуючими чинниками для досягнення високого урожаю зерна кукурудзи на торфових ґрунтах є менш сприятливі мікрокліматичні особливості (менша кількість активного тепла, коротший вегетаційний та без морозний період тощо) порівняно з прилеглими дерново-підзолистими ґрунтами розташованими поряд на суходолі.*

Експериментально встановлено, що в умовах мінімальної тривалості безморозного періоду сформувати повноцінний урожай зерна на осушуваних торфових ґрунтах у зоні Західного Полісся встигнуть лише найбільш ранньостиглі гібриди кукурудзи з ФАО до 220–240. Обравши більш пізньостиглі гібриди існує ризик суттєвого недобору урожаю через передчасне припинення вегетації, спричинене ранніми осінніми заморозками.

Встановлено, що найвищу урожайність кукурудзи на зерно, як на дерново-підзолистих, *так і торфових ґрунтах, забезпечувала органо-мінеральна система удобрення, яка базувалась на внесенні повного мінерального удобрення в нормі $N_{90}P_{90}K_{90}$ на дерново-підзолистих ґрунтах та $N_{35}P_{60}K_{120}$ на торфових ґрунтах у поєднанні з фосформобілізуючим препаратом Райс Пі. Застосування органо-мінеральної системи удобрення ($N_{90}P_{90}K_{90}$ + фосформобілізуючий препарат Райс Пі) забезпечило підвищення урожайності кукурудзи на дерново-підзолистих ґрунтах на 3,02 т/га порівняно з базовою системою удобрення ($N_{30}P_{30}K_{30}$). Застосування органо-мінеральної системи удобрення ($N_{35}P_{60}K_{120}$ + фосформобілізуючий препарат Райс Пі) забезпечило підвищення урожайності кукурудзи на торфових ґрунтах на 5,68 т/га порівняно з природним фоном родючості.*

Ключові слова: *осушувані землі, кукурудза, сорти і гібриди, зона Західного Полісся, зміни клімату, система удобрення*

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NORMALIZED DIFFERENTIAL VEGETATION INDEX OF WINTER WHEAT DEPENDING ON THE RATES OF NITROGEN FERTILIZER AND NITRIFICATION INHIBITOR

S.V. Muntyan[1], Ph.D. in Agricultural Sciences, A.P. Shatkovskyi[2], Doctor of Agricultural Sciences, L.O. Semenko[3], Ph.D. in Agricultural Sciences

[1] Institute of Water Problems and Land Reclamation of NAAS, Kyiv, Ukraine;
https://orcid.org/0000-0002-8933-9283; e-mail: ais_888@ukr.net;
[2] Institute of Water Problems and Land Reclamation of NAAS, Kyiv, Ukraine;
https://orcid.org/0000-0002-4366-0397; e-mail: andriy-1804@ukr.net;
[3] The National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine;
https://orcid.org/0000-0002-4586-3681; e-mail: larisa-s@ukr.net

Abstract. *The article presents the results of experimental studies of the relationship between the normalized differential vegetation index and the yield of winter wheat at different rates of nitrogen fertilizers and the nitrification inhibitor 3.4-dimethylpyrazole phosphate with carbamide-ammonia mixture (CAM-32). Field research was carried out in 2018–2021 in the research department of the Limited Liability Agricultural Company (LLAC) "Druzhba Nova" of the Varvyn district of the Chernihiv region (department of the "Kernel" agricultural holding). Analytical and mathematical and statistical methods were used to process experimental data. The normalized differential vegetation index (NDWI) was determined from the satellite images of WorldView-2, WorldView-3, Geoeye-1 (Maxar USA). The scheme of the one-factor field experiment was the use of options with different rates of nitrogen fertilizers (N_{100} and N_{120}), as well as the use of the nitrification inhibitor 3.4-dimethylpyrazole phosphate in mixture to CAM-32. The control (backgroung) option was the application of fertilizers at the rate of $N_{10}P_{30}K_{40}$. The results of experimental studies proved that NDWI is directly correlated with the yield of winter wheat for all 4 years of research. It was established that the NDWI, on average over three summer months, was higher in 2018 in the range of 0.56–0.67 and in 2020 – 0.53–0.66. The yield of winter wheat was also higher in 2018 and 2020, namely: in 2018 from 3.72 t/ha to 8.14 t/ha and in 2020 – from 3.77 t/ha to 7.25 t/ha. The NDWI, in 2019 and 2021, averaged over three summer months according to the experiment options was lower and amounted to 0.33–0.38 in 2019, and 0.30–0.33 in 2021. This trend correlates with winter wheat yields, which were also low during this period. So, in 2019 it was 3.63 t/ha – 5.10 t/ha and in 2021 – 3.83–4.81 t/ha. The correlation coefficient between NDWI and the yield of winter wheat was high: in July and August, it was from 0.93 to 0.97 on the options with nitrogen fertilizer rates N_{100} and N_{120}.*
Key words: *nitrification inhibitor, 3.4 dimethylpyrazole phosphate, carbamide-ammonia mixture, normalized differential vegetation index, yield, winter wheat*

The relevance of research. Growing crops, as a rule, is carried out over fairly large areas, which makes crop monitoring more difficult and expensive. In addition, each culture has its own different phases of growth and development, phenological rhythms are inherent in it, etc. Therefore, at the present stage of agronomic practice, remote sensing of fields is optimal as a more advanced and accessible technology for monitoring such crops [1–4].

Over the past 40 years, many vegetation indices have been developed and implemented, but the normalized differential vegetation index (NDWI) [5] has become the most widely used. NDWI shows the coverage of the vegetative mass with the difference between the visible and infrared spectrum of radiation. It is essentially a measure of plant health based on the reflectivity at specific frequencies of the various wavelengths being absorbed. This index is most used for monitoring the dynamics of crop vegetation at the regional and global levels [6, 7]. NDWI is also widely used in determining the density of crops, which shows the amount of active photosynthetic biomass [6, 8, 9]. In practice, the processing of digital data and images from satellites provides tools for data analysis through mathematical indices and algorithms [10]. Remote satellite sensors provide digital and graphical data for monitoring of cultivation areas use and changes in the vegetation cover of these areas in approximately real-time at different scales [11, 12]. Crop monitoring by standard methods, such as visual crop diagnosis or sampling, usually requires human resources, time-consuming, lengthy procedures, and is inaccurate for evaluating changes in plant development over large areas [13, 14]. Therefore, we can conclude that the use of crop monitoring using the NDWI index is quite relevant.

Analysis of recent research and publications. An important component in the direction of crops' sensing, despite its shortcomings, is understanding the potential, interpreting the data obtained, fixing errors and the relationship with the final result and sensing goals [5, 15]. Such experiments were carried out in the USA, in the state of Kansas. They concerned the measurement of NDWI and the mapping of crops that were grown in relatively large areas. The accuracy of the measurements was high and amounted to more than 84 % [16]. In addition, field experiments were conducted in Denmark to measure the NDWI index on winter wheat during different growing seasons on the background of different nitrogen's rates application. The use of the NDWI index has been found to be a useful tool, but is dependent on the choice of spectral length [17]. In 2000–2013 Ukrainian scientist I.G. Semenova studied NDWI and established quantitative relationships between the index and the productivity and yield of individual crops for seasonal forecasting for all 25 regions of Ukraine. [18]. Also, the obtained results of experiments on the use of materials taken from the MSU-E space sensor or similar systems proved the possibility of their use for early prediction of the winter wheat productivity with a high level of correlation [19].

Therefore, the **study aimed** to establish the actual correlation between the level of the normalized differential vegetation index NDWI and the grain yield of winter wheat with the use of different rates of nitrogen fertilizers and nitrification inhibitors (NI) in combination with the application of CAM-32.

Research materials and methods. Experimental studies were carried out in the production conditions of the Limited Liability Agricultural Company (LLAC) "Druzhba Nova" of the Varvyn district, Chernihiv region (department of the "Kernel" agricultural holding). The soil of the experimental plot is typical chernozem with low humus, the arable layer is characterized by the following main indicators: humus content – 3.4 %, pH neutral and close to neutral – 5.7–7.0, the content of mobile forms of phosphorus – from high to very high – 15.4–26.3 mg/100 g of soil, exchangeable potassium – from medium to high – 7.1–16.2 mg/100 g of soil, lightly hydrolyzed nitrogen – from high to high – 5.7–7.9 mg/100 g of soil. The studies were carried out according to a single-factor experiment design. The sown area of the experimental plot is 0.6 hectares, and the alternation of options is sequential. Field experiments were laid out and carried out according to the generally accepted methodology for field experiments (Dospehov B.A., 1985). The harvest was taken into account by the method of continuous harvesting and weighing of the bunker mass from each plot, followed by recalculation to standard humidity and weed content according to DSTU 2240-93 in triplicate. Mathematical and statistical calculation of the data was carried out using the Agrostat software and information complex. The normalized differential vegetation index (NDWI) was determined based on the results of images from satellites WorldView-2, WorldView-3, Geoeye-1 (Maxar USA). The images were taken by a separate satellite, depending on its location and cloudiness level, three times during the growing season: in June, July, and August. According to the decision of the regulatory commission of the European Union No. 1257/2014, which corrects the regulation of EC No. 2003/2003 of the European Parliament and the Council regarding fertilizers and changes to supplements I and IV of November 24, 2014, the norm for the use of the ***nitrification inhibitor (NI) 3.4-dimethylpyrazole phosphate has been established (DMPP)*** (EU No. 424-640-9), which ranges from 0.8 % to 1.6 % [20]. Per the regulation, the minimum rate of IN DMPF of 0.8 % was used on amide NH_2^- and ammonium NH_4^+ forms of nitrogen.

According to this minimum calculated rate of 0.8 %, the rate of use of NI DMPP on CAM-32 is 7.02 l per 1000 kg of CAM-32. Accordingly, the calculated rate of IN DMPF for CAM-32with a rate of 250 kg/ha was 1.76 l/ha according to CAM-32 norms, and 300 kg/ha – 2.11 l/ha, respectively.

The following options for applying mineral fertilizer rates were used in the experiment:

1. Background – $N_{10}P_{30}K_{40}$, NPK 7-20-28 granular fertilizers were applied at the rate of 150 kg/ha per sowing.

2. Background+N_{100}+ NI (granulated ammonium sulfate at a rate of 100 kg/ha on frozen soil and CAM-32 at a rate of 250 kg/ha with the application of NI in the spring after the resumption of the vegetation).

3. Background+N_{120}+ NI (granulated ammonium sulfate at a rate of 100 kg/ha on

frozen soil and CAM-32 at a rate of 300 kg/ha with the application of NI in the spring after the resumption of the vegetation).

4. Background+N_{120} (granulated ammonium sulfate at a rate of 100 kg/ha on frozen soil and CAM-32 at a rate of 300 kg/ha without an application of NI in the spring after the resumption of the vegetation).

Research results and discussion. NDWI is a numerical indicator of the condition and number of plants in a certain area of the field. It is calculated by satellite imagery and depends on how plants reflect and absorb light waves of different lengths. According to the study results, winter wheat NDWI for 2018–2021 varied throughout the growing season and was highest in June and decreased in July and August (Table 1). Thus, the NDWI level in June was the highest in the years of research and was at the level of 0.74–0.82 in 2018, 0.69–0.77 in 2019, 0.71–0.80 in 2020 and 0.42–0.48 in 2021. During July and August, NDWI was lower than in June. So, in July, according to the years of research, it was in the range of 0.49–0.60 in 2018, 0.16–0.20 in 2019, 0.47–0.61 in 2020, and 0.23–0.26 in 2021 In August, NDWI was respectively in the range of 0.44–0.58 in 2018, 0.13–0.17 in 2019, 0.42–0.57 in 2020 and 0.24–0.26 in 2021.

If we consider the level of NDWI in the context of field experiment options, then there is a clear tendency to correlate the level of NDWI depending on different rates of nitrogen fertilizers and the application of the nitrification inhibitor (NI) 3.4-dimethylpyrazole phosphate (DMPP) both separately by month and on average over three months. Thus, in 2018, in the control variant $N_{10}P_{30}K_{40}$ (background), the NDWI level was the lowest in June, July and August, 0.74; 0.49 and 0.44, respectively, which averaged 0.56 over three months. With an increase in the nitrogen rate and the addition of NI DMPP, the NDWI increased: in the background+N_{100}+ NI experiment in June, July, and August, the NDWI was 0.79; 0.57 and 0.55, which averaged 0.64 over three months.

NDWI slightly increased in the variant of the experiment with an increased nitrogen rate – background+N_{120}+ NI – and was 0.80 in June, July and August; 0.59 and 0.57, which averaged 0.65 over three months. The highest level of NDWI was in the variant of the experiment with an increased nitrogen rate, but without the use of NI – background+N_{120} – and was 0.82 in June, 0.60 in July and 0.58 in August, and on average over three months – 0.67. A similar trend was observed during other years of research. The lowest NDWI level was observed on the control variant $N_{10}P_{30}K_{40}$ (background) in June, July and August and on average for three months in 2019, namely: 0.69; 0.16; 0.13 and 0.33, in 2020 – 0.71; 0.47; 0.42 and 0.53 and in 2021 – 0.42; 0.23; 0.24 and 0.30. The level of NDWI increased with an increase in the nitrogen rate and the addition of NI DMPP. Thus, in the experimental option – background + N100 + NI – the NDWI level in 2019 in June, July and August was 0.74; 0.19; 0.16 and on average for three months 0.36;

1. Normalized differential vegetation index of winter wheat depending on the application of different rates of nitrogen fertilizers with the addition of a nitrification inhibitor (2018–2021)

Experiment options	Month	Years of research				Correlation coeficient
		2018	2019	2020	2021	
$N_{10}P_{30}K_{40}$ (background)	June	0.74	0.69	0.71	0.42	–0.67
	July	0.49	0.16	0.47	0.23	0.25
	August	0.44	0.13	0.42	0.24	0.38
	Average	0.56	0.33	0.53	0.30	–
Background+N_{100}+ NI	June	0.79	0.74	0.77	0.46	0.71
	July	0.57	0.19	0.55	0.25	0.97
	August	0.55	0.16	0.54	0.28	0.93
	Average	0.64	0.36	0.62	0.33	–
Background +N_{120}+NI	June	0.80	0.74	0.78	0.47	0.75
	July	0.59	0.18	0.61	0.25	0.94
	August	0.57	0.15	0.55	0.27	0.93
	Average	0.65	0.36	0.65	0.33	–
Background +N_{120}	June	0.82	0.77	0.80	0.48	0.70
	July	0.60	0.20	0.61	0.26	0.97
	August	0.58	0.17	0.57	0.26	0.97
	Average	0.67	0.38	0.66	0.33	–

in 2020, respectively – 0.77; 0.55; 0.54 and 0.62 and in 2021 – 0.42; 0.23; 0.24 and 0.30. In the experiment variant – background + N_{120} + NI – the NDWI level in 2019 in June, July, and August was 0.74; 0.18; 0.15, and on average for three months 0.36; in 2020, respectively, 0.78; 0.61; 0.55 and 0.65 and in 2021 – 0.47; 0.25; 0.27 and 0.33.

The highest level of NDWI was observed in the variant with an increased nitrogen rate – background + N_{120}, but without the application of NI DMPP. Thus, the NDWI level in 2019 in June, July and August was 0.77; 0.20; 0.13 and on average for three months 0.38; in 2020 0.80; 0.61; 0.57 and 0.66, respectively, and in 2021 – 0.48; 0.26; 0.26 and 0.33. The correlation coefficient was high: in July and August in the variants of the experiment – background+N_{100}+ NI at the level of 0.93–0.97, in the variant – background+N_{120}+ NI at the level of 0.93–0.94 and in the variant – background+N_{120} – 0.97.

As for NDWI indicators of winter wheat in terms of years of research, the trend of dependence of NDWI on meteorological parameters can be traced. Thus, on average over three months in the section of all variants of the experiment, NDWI was higher in 2018 (0.56–0.64) and in 2020 (0.53–0.66), which is associated with the optimal water regime of the soils. On the other hand, in 2019 and 2021, the NDWI values on average for three months across all variants of the experiment were lower and ranged from 0.33 to 0.38 and 0.30–0.33, respectively. In a mixture with CAM-32 NI DMPP makes it possible to preserve the main supply of mineral nitrogen for a longer period until the moment when it is most needed by wheat plants. It is NI DMPP in a mixture with CAM-32 that is able not only to prolong the use of available nitrogen in the soil but also to significantly optimize its assimilation by plants. Table 2 shows data on the yield of winter wheat depending on different rates of nitrogen fertilizers and the use of NI DMPP as an addition to CAM-32 and their combined use.

According to the results of the research, the yield of winter wheat varied by year. Thus, the highest yield was obtained in 2018, when it ranged from 3.72 t/ha to 8.14 t/ha (LSD_{05} in 2018 was 1.33 t/ha) and in 2020 – from 3.77 t/ha to 7.25 t/ha (LSD_{05} in 2020 was 2.03 t/ha). A relatively lower level of winter wheat grain yield was observed in 2019: from 3.63 t/ha to 5.10 t/ha with LSD_{05} 1.86 t/ha and in 2021 – from 3.83 t/ha to 4.81 t/ha with LSD_{05} 2.49 t/ha. The average grain yield of winter wheat according to the experimental options during 2018–2021 ranged from 3.74 t/ha to 6.30 t/ha.

A clear trend towards an increase in the yield of winter wheat has been established, both individually by year and on average over 4 years of research with an increase in the application rate of nitrogen fertilizers and the use of NI DMPP.

Thus, the lowest yield of winter wheat was obtained in the control option with the application of $N_{10}P_{30}K_{40}$ (background), where it was 3.72 t/ha in 2018, 3.63 t/ha in 2019, 3.77 t/ha in 2020 and 3.83 t/ha in 2021, which averaged 3.74 t/ha over 4 years. With an increase in the rate of nitrogen fertilizers and the use of NI DMPP, the yield of winter wheat increased. So, on the variant – background+N_{100}+NI, the yield of winter wheat was 8.00 t/ha in 2018, 5.05 t/ha in 20219, 7.20 t/ha in 2020, and 4.81 t/ha in 2021, which averaged 6.27 t/ha over the 4 years of research. With a further increase in the rate of nitrogen fertilizers and the application of NI DMPP, the yield of winter wheat also increased. The only exception was 2021, when in the background+N_{120}+NI option, the yield of winter wheat was 8.14 t/ha in 2018, 5.10 t/ha in 2019, and 7.25 t/ha in 2020 and 4.72 t/ha in 2021, which averaged 6.30 t/ha over 4 years of research. With the application of the maximum rate of nitrogen fertilizers, but without the use of NI DMPP (background+N_{120}), the yield was higher than the control option ($N_{10}P_{30}K_{40}$ (background), but lower than the options with the same rate of nitrogen fertilizers and the use of NI DMPP (background+N_{120}+ NI) and the option with a reduced rate of nitrogen fertilizers

2. Grain yield of winter wheat depending on the application of various rates of nitrogen fertilizers with the addition of a nitrification inhibitor (2018–2021), t/ha

Experiment option	**Yield, t/ha**				**Average productivity 2018–2021, t/ha**
	2018	**2019**	**2020**	**2021**	
$N_{10}P_{30}K_{40}$ (background)	37.2	36.3	37.7	38.3	37.4
Background+N_{100}+NI	80.0	50.5	72.0	48.1	62.7
Background +N_{120}+NI	81.4	51.0	72.5	47.2	63.0
Background +N_{120}	74.0	46.4	68.5	45.0	58.5
LSD_{05}	1.33	1.86	2.03	2.49	–

and using DMPP NI (background+N_{100}+NI). So, in the option – background+N_{120} – the yield was 7.40 t/ha in 2018, 4.64 t/ha in 2019 year, 6.85 t/ha in 2020 and 4.50 t/ha in 2021, which averaged 58.5 t/ha over the 4 years of research.

Conclusions. According to the results of experimental studies, it has been proven that NDWI correlates with the yield of winter wheat grain. It was found that NDWI during the summer growing season of winter wheat plants in the context of experimental variants was higher in 2018 and 2020 and amounted to 0.56–0.67 and 0.53–0.66, respectively. The grain yield of winter wheat was also higher in these years of research: in 2018 – from 3.72 t/ha to 8.14 t/ha and in 2020 – from 3.77 t/ha to 7.25 t/ha. During 2019 and 2021, NDWI indicators on average for three summer months in the context of experience options were lower and amounted to 0.33–0.38 in 2019 and 0.30–0.33 in 2021. Winter wheat grain yield was also at its lowest level in these years of study: in 2019 ranging from 3.63 t/ha to 5.10 t/ha and in 2021 – from 3.83 t/ha to 4.81 t /ha. The correlation coefficient between NDWI and winter wheat yield was the highest in July and August in the variants: background+N_{100}+NI; background+N_{120}+NI and background+N_{12}0 and ranged from 0.93 to 0.97. So, the possibility and feasibility of using of this indicator for remote monitoring of the condition of winter wheat crops have been confirmed.

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НОРМАЛІЗОВАНИЙ ДИФЕРЕНЦІЙНИЙ ВЕГЕТАЦІЙНИЙ ІНДЕКС ПШЕНИЦІ ОЗИМОЇ ЗАЛЕЖНО ВІД НОРМ АЗОТНИХ ДОБРИВ ТА ІНГІБІТОРА НІТРИФІКАЦІЇ

С.В. Мунтян[1], канд. с.-г. наук, А.П. Шатковський[2], докт. с.-г. наук, Л.О. Семенко[3], канд. с.-г. наук

[1] Інститут водних проблем і меліорації НААН, Київ, Україна;
https://orcid.org/0000-0002-8933-9283; e-mail: ais_888@ukr.net;
[2] Інститут водних проблем і меліорації НААН, Київ, Україна;
https://orcid.org/0000-0002-4366-0397; e-mail: andriy-1804@ukr.net;
[3] Національний університет біоресурсів та природокористування України, Київ, Україна;
https://orcid.org/0000-0002-4586-3681; e-mail: larisa-s@ukr.net

Анотація. *У статті наведено результати експериментальних досліджень із вивчення взаємозв'язку між нормалізованим диференційним вегетаційним індексом та врожайністю пшениці озимої за використання різних норм азотних добрив та інгібітора нітрифікації 3,4-диметилпіразолфосфат з КАС-32. Польові дослідження проведено протягом 2018–2021 рр. у науково-дослідному відділі СТОВ «Дружба Нова» Варвинського району Чернігівської області (відділення агрохолдингу «Кернел»). Для обробки експериментальних даних використано аналітичні та математично-статистичні методи. Нормалізований диференційний вегетаційний індекс (NDWI) визначали за результатами знімків із супутників WorldView-2, WorldView-3, Geoeye-1 (Maxar USA). Схемою однофакторного польового досліду було використання варіантів із різними нормами азотних добрив (N_{100} та N_{120}), а також використання інгібітора нітрифікації 3,4-диметилпіразолфосфат при додаванні в КАС-32. Контрольним був варіант із внесенням добрив у нормі $N_{10}P_{30}K_{40}$. Результатами експериментальних досліджень доведено, що NDWI прямо корелює з урожайністю пшениці озимої за всі 4 роки досліджень. Встановлено, що NDWI в середньому за три місяці за варіантами досліду був вищим у 2018 р. у межах 0,56–0,67 та в 2020 р. – 0,53–0,66 Врожайність пшениці озимої також була більшою в 2018 та 2020 роках, а саме: у 2018 р. від 3,72 т/га до 8,14 т/га та у 2020 р. – від 3,77 т/га до 7,25 т/га. В 2019 р. та у 2021 р. NDWI в середньому за три літні місяці за варіантами досліду був нижчим та складав: у 2019 р. 0,33–0,38, у 2021 р. – 0,30–0,33. Ця тенденція корелюється з урожайністю пшениці озимої, яка також була на нижчому рівні в цей період. Так, у 2019 р. вона становила від 3,63 т/га до 5,10 т/га та у 2021 р. – 3,83–4,81 т/га. Коефіцієнт кореляції між NDWI та врожайністю пшениці озимої був високим: у липні та серпні на варіантах із нормами азотних добрив N_{100} і N_{120} становив від 0,93 до 0,97.*

Ключові слова: *інгібітор нітрифікації, 3,4 диметилпіразолфосфат, карбамідно-аміачна суміш, нормалізований диференційний вегетаційний індекс, урожайність, пшениця озима*

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ANALYSIS OF APPLYING SURFACE WATER TREATMENT TECHNOLOGY WHEN USING CHLORINE DIOXIDE AT WATER SUPPLY PLANTS

E.O. Mavrykin, Ph.D. student
Institute of Water Problems and Land Reclamation of the National Academy of Agricultural Sciences of Ukraine, Kyiv, Ukraine;
https://orcid.org/0000-0002-6193-8890; e-mail: evgeniy_mavrikin@ukr.net

Abstract. *The results of the conducted research made it possible to establish that in EU countries chlorine dioxide (CD) is more often used for secondary or final disinfection of drinking water. By-products of this process are chlorites and chlorates, which are subject to control in the drinking water of all EU countries. Aldehydes and carboxylic acids can also be formed in drinking water, which leads to a decrease in the microbiological stability of tap water. Ozonation and filtration using a carbon filter are used in the final stage of drinking water purification, which contributes to a significant reduction in the dose of CD and water contamination with toxic chlorites. In the case of pre-oxidation of water with sodium hypochlorite, the largest amount of chlorites and chlorates is formed, while in the case of using potassium permanganate for the same purpose, the need for CD and the amount of chlorites and chlorates in drinking water reduced. Chlorination of natural water that has undergone CD pre-oxidation leads to complete oxidation of the chlorites that have formed, increases the effectiveness of disinfection, and provides a bacteriostatic effect in the distribution network. During 2021–2022, when using CD for the treatment of drinking water at the Dniprovska WTP in Kyiv it was established that the process of treating natural water with CD is accompanied by the formation of its by-products, mainly toxic chlorites, the levels of which depend on the applied doses of CD and are the lowest in winter, while the largest ones are observed in summer and do not always reach regulatory values (0.2 mg/l) and range up to 0.7 mg/l, which corresponds to the WHO recommended standard for this substance in drinking water. Italian scientists focus their attention on the fact that during the first years of using CD at each water supply station, optimal conditions must be ensured for the safe and effective use of this reagent. Therefore, CD is becoming widespread in the EU countries and Ukraine for the treatment of tap drinking water; it is an alternative method of water effective disinfection at water supply stations with traditional surface water purification technology. Using such a method for treating surface water requires a preliminary pilot experiment and should be carried out along with an analysis of the feasibility of using the methods for preliminary and/or final purification of drinking water from organic substances and additional disinfection. Today, based on experimental and natural studies, it is relevant to expand knowledge about the properties of CD in the case of its use in drinking water supply for the treatment of surface water with a high content of organic substances.*

Key words: *chlorine dioxide, chlorites, oxidation by-products, water supply stations*

Relevance of research. For the population of Ukraine, as in many European countries, the problem of providing drinking water of guaranteed quality is particularly relevant [1]. Data from scientific sources indicate the unsatisfactory quality of surface water in Ukraine in general and their critical condition in certain regions. Its condition is directly related to the composition and volume of return water, in particular, the efficiency of wastewater treatment and disinfection at sewage treatment plants in settlements and industrial enterprises. Climate change also has a significant negative impact on surface water quality [2–4]. Screening monitoring of the Dnipro River basin showed extremely high levels of predicted safe concentrations in water of herbicides, insecticides, fungicides, as well as pharmaceutical substances such as carbamazepine, lopinavir, diclofenac, efavirenz, etc.

As a result of the intensive inflow of biogenic compounds into rivers and reservoirs, the latter have a massive development of phytoplankton, which complicates the processes of treating high-quality drinking water at water supply stations (WSS) [5]. In the zone of active hostilities, providing a drinking water supply to the population is a particularly difficult task. Enterprises of centralized drinking water supply bear the burden of problems due to the non-guaranteed quality of the source water, the lack of stable conditions for the technological process of water treatment as well as for the operation of water treatment facilities and networks, etc. [6, 7].

Thus, in general, in the current conditions of anthropogenic load and climate change, which negatively affect the quality of surface water, namely, lead to an increase in the concentration of the organic component of water pollution, deterioration of microbiological indicators, etc., traditional coagulants and disinfectants are not able to ensure the normative quality of drinking water [8]. Disinfection is the priority process of its treatment. Due to the low cost, ease of operation, high efficiency, and stability in the distribution network, drinking water is chlorinated (with chlorine or sodium hypochlorite), but the identified shortcomings of the chlorination process became the basis for the application of chlorine dioxide (CD) in disinfecting tap drinking water [9–11].

Scientists have carried out a wide range of research on the properties of CD, in particular, when applying it at water supply stations, the advantages of using CD for disinfection of drinking water compared to chlorine, its disadvantages, features of combined action with other disinfectants, etc. However, today disinfection of drinking water with CD is becoming widespread in the EU countries and Ukraine [12]. Scientists emphasize the relevance of researching and analyzing an appropriate applied technology for each drinking water supply station, primarily due to the large difference in the composition of the source water and the applied technological approaches at WSS [13]. Because of the above, we analyzed data from the scientific sources on the experience of using CD at WSS.

Analysis of recent research and publications. For the first time in the world, CD was used to disinfect drinking water in Germany in 1894. The use of this reagent in water supply was restrained for a long time, but after solving the problem of industrial production of sodium chlorite, which is the main component in obtaining CD, as well as after establishing the fact that in the process of chlorination carcinogenic organochlorine is formed in water, CD started to be used for decontamination of tap drinking water [14, 15]. At the end of the 20th century, this reagent was already widely used, primarily for the secondary disinfection of drinking water at water treatment plants in the USA and Western Europe, and it also began to be used in Ukraine [16–18]. Today it is used for treating municipal water supply in 13 EU countries – Austria, Finland, France, Germany, Greece, Hungary, Italy, Luxembourg, Poland, Portugal, Romania, Slovenia, and Spain [19].

The purpose of the scientific research is to analyze the features of using CD for surface water treatment based on literary sources regarding the relevant field studies conducted.

Research materials and methods. Theoretical methods of scientific research such as analysis and synthesis, comparison, classification, and generalization were used in the study.

Research results and their discussion. Based on the analytical studies, it was established that in the EU countries, CD is more often used for secondary or final disinfection of drinking water, in particular for the treatment of surface water at the stage of disinfection after preliminary ozonation and before UV disinfection. For example, in the south-east of Poland in the Subcarpathian Voivodeship, there are the following water intakes and their water treatment technologies: A – the Wisłok River (capacity – 84,000 m^3/day, drinking water treatment technology: preliminary ozonation, coagulation, filtration (anthracite-sand layer), secondary ozonation, filtration (carbon layer), Cl2 disinfection, CD, UV disinfection); B – the Yasiolka River (capacity – 7000 m^3/day, drinking water treatment technology: preliminary oxidation, coagulation, filtration (sand-gravel layer), CD disinfection, UV disinfection); C – the Besko reservoir (17,000 m^3/day, drinking water treatment technology: preliminary oxidation, coagulation, filtration (anthracite-sand layer), CD disinfection, UV disinfection) [20].

Following the literature data, by-products are formed in drinking water after CD disinfection, the main of which are chlorites (standard by Directive 2020/2184/EU – ≤ 0,7 mg/l) and chlorates (standard by Directive 2020/2184/ EU – ≤ 0,7 mg/l), which are subject to control in drinking water in all EU countries. In particular, 50–70 % and 0–10 % of applied CD are transformed into chlorite and chlorate, respectively [21]. Carboxylic acids and aldehydes – low molecular weight organic compounds with high biodegradability can also be formed in drinking water treated with CD. CD, like ozone, reacts with organic substances in surface water as a result of which aldehydes are formed. Their presence in the water supply network is extremely undesirable due to the possibility of secondary growth of microorganisms present in running water and forming biofilms on the inner walls of distribution pipes, especially when the disinfectant remains disappear at the same time [22–27].

The other researchers [13], in the city of Poznań (Poland), conducted a research for several years on the method of using CD in the centralized drinking water supply for the treatment of surface water with high reactivity of natural organic matter, which led to a decrease in the microbiological stability of water. A particular increase in this phenomenon was observed after using CD for secondary disinfection. The sourse water of the Mosina WTP, located approximately 20 km from Poznań, is a mixture of groundwater and infiltration water (40 %) of the wells drilled on the shoreline in the Warta River dam to reduce organic matter in source water.

Despite numerous attempts, it was impossible starting use only CD due to the growth of psychrophilic bacteria in the water supply system. Therefore, the water was constantly disinfected with a mixture of two agents: gaseous chlorine and CD in a ratio of 60–40 %. However, mixing disinfectants with a seasonal change in their rate was not completely effective and worsened the organoleptic parameters of the water.

Cast iron and PVC/PE are the basic materials of the pipes; there are some sections of the water supply pipeline, which are made of asbestos-cement pipes, which can be successively replaced. The age of almost half of the pipes is 10–40 years; 15 % of the network was constructed more than 40 years ago [28]. Modernization of the WTP was carried out during 2010–2015, which primarily included the construction of the facilities for the final stage of purification, which involved ozonation and sorption with activated carbon, as well as an increase in the capacity of the WWTP from 100.000 to 150.000 m^3/day, while liquid chlorine was replaced with sodium hypochlorite. Figure 1 shows which technologies are correlated with the CD rate used at the Mosina WTP.

After the two-stage treatment, the water at the Mosina WTP was characterized by a reduced content of disinfection by-products and organic substances, which led to a decrease in the need for disinfectants. In 2015, the leaching of organic compounds, which were in the water supply network before the reconstruction was observed (in 2019, it was not observed) [13].

Another article presents the results of experiments conducted at the Fortore (Foggia, Southern Italy) and Mosina (Poznan, Poland) WTPs. Chlorine was added to the CD solution used for preliminary water disinfection.

The results showed high chlorite removal efficiency on GAC filters up to 5.500 and 10.000 bed volumes for mineral and vegetable GAC at Fortore and up to 11.000 bed volumes at Mosina. Natural organic matter (NOM) dissolved in raw Fortore water was also characterized. The presence of small molecules (< 500 Da) in water that was previously disinfected led to the formation of trihalomethanes (THM) and carboxylic acids due to a rapid reaction with Cl_2-ClO_2. Low molecular weight carboxylic acids are effectively removed from water during filtration through biologically active carbon layers. GAC filters showed removal percentages from 60 to 72 % for THM and from 14.6 to 43 % for total organic carbon (TOC) [29].

CD is usually used in medium and large drinking water treatment plants due to high production and management costs. Practical experience has shown that the service life of polyethylene pipes is significantly reduced due to

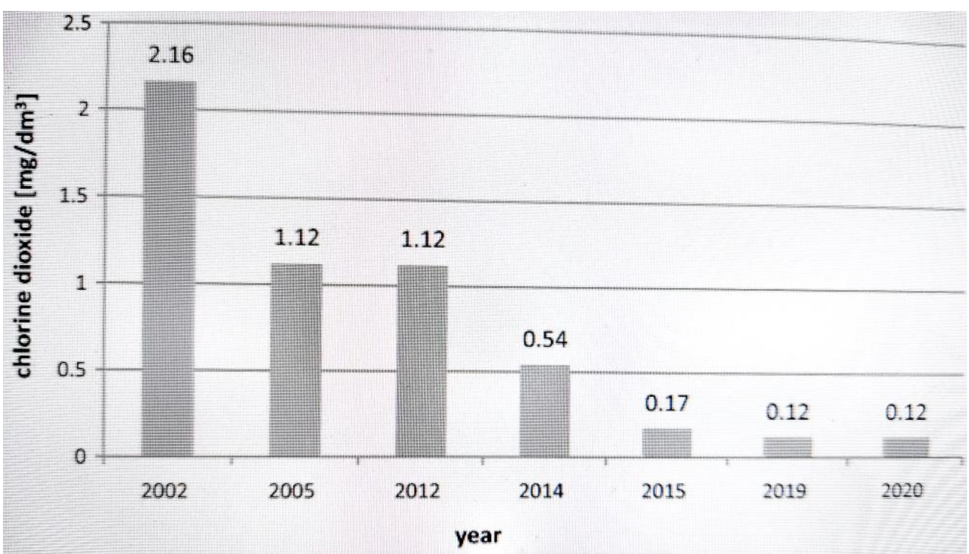

Fig. 1. Dynamics of CD rates depending on the drinking water treatment technology at the second stage: 2005 – modernization of post-filters for cleaning from iron and manganese compounds; 2012 – a new aeration plant was put into operation; 2014 – powdered coal was dosed; 2015 – the entire technological line was put into operation, including ozonation and filtration through a carbon filter (without powdered coal)

their being affected by the water with CD. The CD is more aggressive to plastic pipes, in particular polyethylene (PE) ones than other chlorine-based disinfectants. That can be explained by the fact that CD is a dissolved gas that diffuses faster into the polymer compared to other disinfectants that accelerate degradation reactions. Recently, many companies have offered new polyethylene pipes with a modified formulation, more resistant to CD. However, there is still no standardized test method for evaluating the long-term performance of polyethylene pipes. Further experiments are necessary to correlate the parameters of the chemical and mechanical characteristics of polyethylene pipes with their service life [30].

According to the research results of Italian scientists, it has been established that in the case of preliminary oxidation of water with sodium hypochlorite, the need for CD is high, and the largest amount of chlorites and chlorates is formed. At the same time, in the case of preliminary oxidation with potassium permanganate, coagulation with both iron chloride and aluminum sulfate reduces the need for CD, as well as the number of chlorites and chlorates in drinking water. Activated carbon reduces the content of CD by about 50 % and leads to a decrease in the formation of chlorite and chlorate [31].

Data from field studies on the combined use of CD and chlorine for the treatment of surface water in five cities of Ukraine (Zaporizhia, Dnipro, Sevastopol, Kremenchuk, Zhovti vody) showed that the most optimal is the use of CD for primary disinfection, while chlorine (liquid or sodium hypochlorite) is effective to be used at the stage of post-disinfection. Depending on the quality of the source water, the effective rate of CD at the pre-oxidation stage is 1.0–1.5 mg/l, which is 3–4 times less than the CD rate sufficient to achieve a similar effect. Chlorination of natural water that underwent peroxidation with CD leads to complete oxidation of formed chlorites, increases the effectiveness of disinfection, and provides a bacteriostatic effect (prolonged effect) in the distribution network [32].

By the literature sources, at the stage of industrial research (2017) on the use of CD for the treatment of drinking water at the Dniprovska WTP in Kyiv city, for primary disinfection a rate of 1.2–1.5 mg/l was used [15], for the secondary disinfection – 0.3–0.45 mg/l, and after its introduction into the technological process (2021-2022) [33] – 0.8–2.5 mg/l, and 0.2–0.6 mg/l respectively. Before entering clean water tank (CWT), the water undergoes the stages of treatment with CD, coagulation (with aluminum sulfate and iron chloride), settling, filtering, and disinfection with CD. The process of treating natural water with CD is accompanied by the formation of its by-products, mainly toxic chlorites, the concentrations of which depend on the applied rates of CD and are the lowest in winter and the largest in summer. In the summer period, the maximum concentration of chlorites in drinking water from CWT can be higher than the national hygienic standard (0.2 mg/l) and range up to 0.7 mg/l, which corresponds to the WHO recommended standard for this substance in drinking water. Based on the hygienic assessment of individual options for using CD in technology of drinking water preparation from surface sources compared to traditional chlorine technology, the advantages of using CD in water treatment instead of ordinary chlorine at the initial and final stages of surface water treatment are shown.

Italian scientists emphasize that in the case of applying CD, the staff of each WTP accumulate their own experience for the implementation of the optimal technological process. During the first years of applying CD, the personel at WTP should elaborate on their optimal conditions for the safe and effective use of this reagent. Correctly conducted pilot studies are a mandatory element of planning modernization changes in water supply facilities [13].

Conclusions. The CD is becoming widespread both in the EU countries and in Ukraine for the treatment of tap drinking water. It is an alternative method of an effective disinfection for water treatment plants with traditional surface water purification technology. It was established that the use of CD for surface water treatment requires a preliminary pilot experiment and should be carried out together with an analysis of the feasibility of using methods for preliminary and/or final purification of drinking water from organic substances and additional its disinfection. Thus, today it is relevant, based on experimental and natural studies, to expand knowledge about the properties of CD in the case of its use for the treatment of surface water with a high content of organic substances in the field of drinking water supply.

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АНАЛІЗ ЗАСТОСУВАННЯ ТЕХНОЛОГІЇ ОБРОБКИ ПОВЕРХНЕВОЇ ВОДИ ДІОКСИДОМ ХЛОРУ НА ВОДОПРОВІДНИХ СТАНЦІЯХ

Є. О. Маврикін, аспірант

Інститут водних проблем і меліорації НААНУ, Київ, Україна
https://orcid.org/0000-0002-6193-8890; e-mail: evgeniy_mavrikin@ukr.net

Анотація. *Результати проведених досліджень дозволили встановити, що в країнах ЄС діоксид хлору (ДХ) частіше використовують для вторинного або заключного знезараження питної води. Побічними продуктами такого процесу є хлорити та хлорати, що підлягають контролю у питній воді всіх країн ЄС, а також у питній воді можуть утворюватися альдегіди і карбонові кислоти, що призводить до зниження мікробіологічної стабільності водопровідної води. Через зазначене на заключному етапі очищення питної води використовують озонування та фільтрацію через вугільний фільтр, що сприяє суттєвому зменшенню дози ДХ та забрудненню води токсичними хлоритами. У разі попереднього окиснення води гіпохлоритом натрію утворюється найбільша кількість хлоритів та хлоратів, а у разі використання з цією ж метою перманганату калію знижується потреба у ДХ та кількість хлоритів та хлоратів у питній воді. Хлорування природної води, що пройшла преокиснення ДХ, призводить до повного окиснення хлоритів, які утворилися, підвищує ефективність знезараження та забезпечує бактеріостатичний ефект у розподільній мережі. Протягом 2021–2022 рр. використання ДХ для обробки питної води на Дніпровській ВС м. Києва встановлено, що процес обробки природної води ДХ супроводжується утворенням у ній його побічних продуктів, переважно токсичних хлоритів, рівні яких залежать від застосовуваних доз ДХ і є найменшими взимку, а найбільшими – влітку та не завжди досягають нормативних значень (0,2 мг/л) і коливаються у межах до 0,7 мг/л, що відповідає рекомендованому ВООЗ нормативу для цієї речовини у питній воді. Італійські науковці акцентують свою увагу на тому, що протягом перших років використання ДХ на кожній водопровідній станції повинні забезпечуватись свої оптимальні умови для безпечного та ефективного використання цього реагенту. Отже, ДХ набуває поширення в країнах ЄС та Україні для обробки водопровідної питної води, є альтернативним методом її ефективного знезараження на водопровідних станціях із традиційною технологією очищення поверхневої води. Застосування такого методу для обробки поверхневої води потребує попереднього пілотного експерименту та повинно здійснюватися разом з аналізом доцільності застосування методів для попереднього та/або заключного очищення питної води від органічних речовин та додаткового її знезараження. На сьогодні є актуальним на підставі експериментальних та натурних досліджень розширити знання щодо властивостей ДХ у разі його використання в практиці питного водопостачання для обробки поверхневої води з високим вмістом органічних речовин.*

Ключові слова: *діоксид хлору, хлорити, побічні продукти окиснення, водопровідні станції*

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