Irrigation in the Ukrainian Black Sea region during the state of war and post-war recovery - soil and environmental consequences.

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The general problem statement and relevance of the topic are as follows:

It is well-known that the necessity for drainage and irrigation measures is determined by specific natural conditions.

The Ukrainian Black Sea region is characterized by unfavorable water regimes and a deficit of productive moisture during the growing season.

Climate change and military aggression create a state of constant uncertainty in the region's economic conditions, necessitating adaptation to these transformations.

Undoubtedly, the most radical step in this situation is the restoration/construction of irrigation systems in the region.

In doing so, we must remember the importance of soils in irrigation systems, their ecological-productive functions, and their potential.

- Monitoring of irrigated and adjacent lands is an integral part of the state environmental monitoring system and is carried out with the aim of ensuring the rational use of land and water resources, identifying reasons for their unsatisfactory condition, quality, and pollution, timely implementation of reclamation measures to prevent soil degradation and harmful effects of water (including flooding), restoration of soil fertility, protection of water and land from pollution, and timely repair (reconstruction) of reclamation systems.

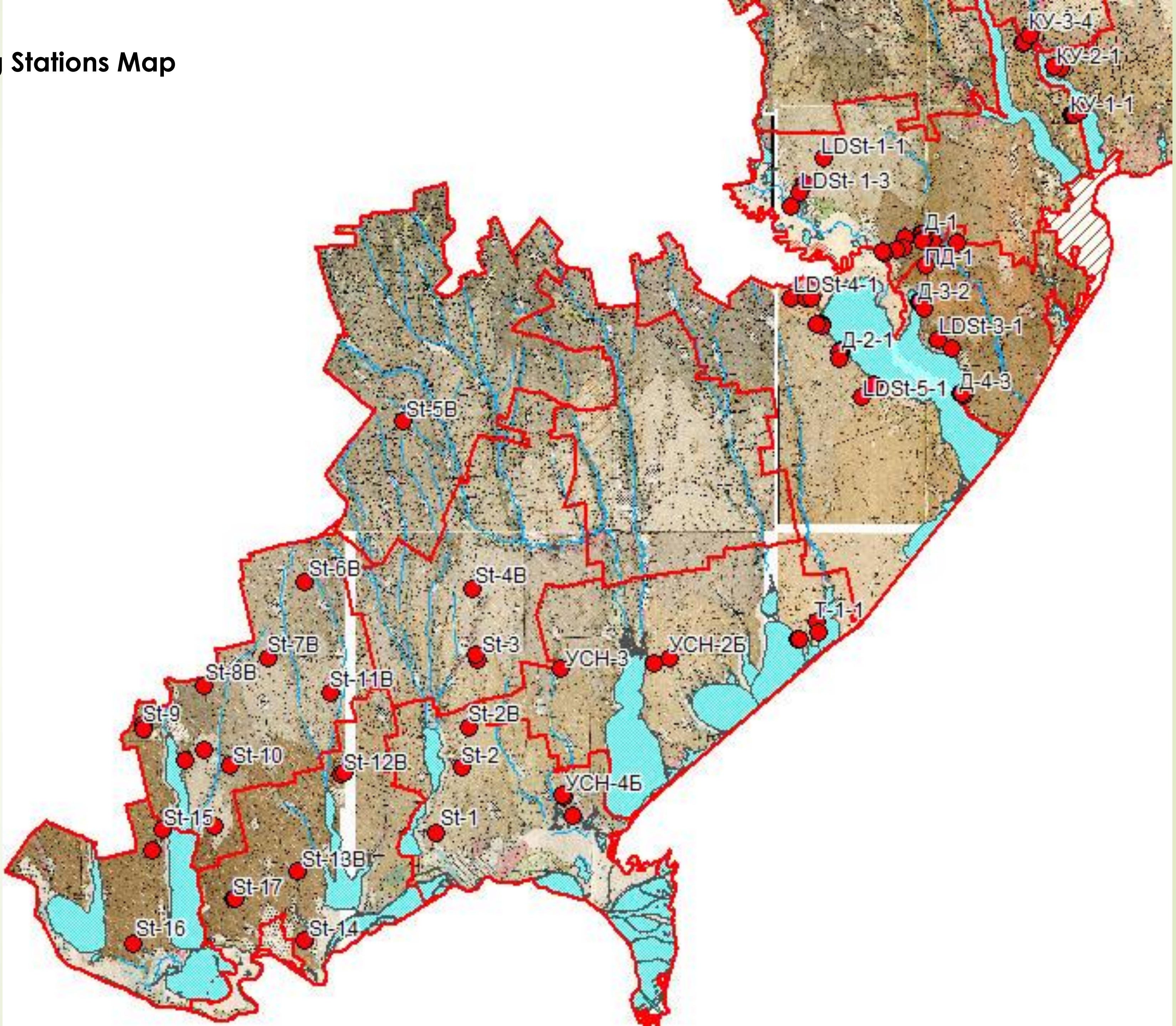
- In the Odessa region, there are 231.25 thousand hectares of reclaimed lands, including 53 irrigation systems covering an area of 226.86 thousand hectares. Among them, there are 5 rice systems covering 13.68 thousand hectares. The drained lands occupy an area of 4.39 thousand hectares. Additionally, there are 15.39 thousand hectares of adjacent lands under control. The area of lands provided with drainage in the region is 41.99 thousand hectares, including 40.20 thousand hectares under irrigation.

- Thus, the total area of all lands under control is 246.64 thousand hectares. The irrigated lands of the region are located within the territories of three river basin districts: the Danube River basin (sub-basin of the Lower Danube), the Dniester River basin, and the Black Sea region river basin.

- The general monitoring of irrigated lands is conducted through stationary observation areas. According to the hydrogeological and reclamation assessment, the area of lands with unfavorable conditions amounts to 14 thousand hectares. This includes 8.6 thousand hectares affected by an unacceptable depth of groundwater level, 4.5 thousand hectares due to soil salinization and sodification, and 1.1 thousand hectares affected by a combination of both factors.

- Until May 1 of the current year, this monitoring was carried out by a separate unit, the "Black Sea Water Resources and Soil Center" (BSWRSC), which is a part of the Basin Management of Water Resources of the Black Sea and Lower Danube Rivers, in collaboration with the Department of Geography of Ukraine, Soil Science, and Land Cadastre, and the Problem Scientific Research Laboratory of Soil Geography and Soil Cover Protection of the Chernozem Zone (PSRL-4) at Odessa I.I. Mechnikov National University.

Groundwater Monitoring Stations Map



- USN, St, LDSt, T, KU, D, PD - groundwater monitoring stations

D-1, PD-1, USN-2…7, St 10, 15 - investigation sites within irrigation arrays

- DSS-1 Petrodolinska - Nyzhnednistrovska Irrigation System (IS): This area consists of moderately dissected Black soils of the southern moderate facies within a watershed plain. Irrigation with waters from the Dniester River started in 1988, with an average mineralization level of 0.7-0.9 g/dm3. In the last four years, irrigation has not been applied (in a post-irrigation evolution regime). Soil samples were collected from irrigated vegetable crop rotations in these farms, both during the irrigation and post-irrigation (harvesting) periods, for the determination of agrochemical and physico-chemical properties. Similar soil samples were taken from adjacent non-irrigated (rain-fed) fields with comparable geomorphological, geological, and soil conditions. Due to the localized nature of soil moisture during drip irrigation, samples were taken under the drip and in the center between rows, which remain dry under drip irrigation conditions.

- DSS-2 Trapivska - 1st stage of the Danube-Dniester Irrigation System within the Sasik-Saratsky agro-reclamation and soil district: This area consists of southern Black soils of the warm facies within a watershed plain. Irrigation with chloride-sodium waters from the Sasik reservoir began in 1983, with an average mineralization level of 1.5 to 2.0 g/dm3. Over the last 27 years, irrigation has not been applied (in a post-irrigation evolution regime).

- DSS-3 Bashtanivska - northern part of the Tatarbunar Irrigation System within the Dmytriv-Tatarbunar agro-reclamation and soil district: This area consists of southern Black soils of the warm facies within a watershed plain. Irrigation is done with transformed water from the Dmytriv reservoir, which has a sulfate-sodium chemical composition, with a mineralization level ranging from 0.8 to 1.0 (1.2) g/dm3 during the irrigation season. In the last 25 years, irrigation has been irregular, and from 2012, drip irrigation has been used for cultivating vegetable crops. In 2015, a cherry orchard was planted in this area, with a spacing of 4 meters between rows and 2 meters between trees in rows. The trees are irrigated using the drip irrigation method, and soil moisture in the irrigated zone reaches a depth of 120-140 (150) cm, stabilizing at 80-90 (95) % of field capacity during the vegetation period.

- DSS-4 Desantnenska – southern part of the Tatarbunar Drainage System within the Kiliya-Desantnensk Agromeliorative and Soil Reclamation District. Lower Danube Terrace Plain. Geochronologically subordinate landscape. Southern Chernozems of the warm phase. Irrigation with freshwater (0.3-0.5 g/dm3) hydrocarbonate-calcium waters from the Danube River. Over the last 26 years, it has not been irrigated.
- DSS-5 Desantnenska Rice – Michurinska Rice Drainage System within the Lower Danube Floodplain-Floodplain Agromeliorative and Soil Reclamation District. High level of Danube floodplain. Geochronologically subordinate super-aqual landscape. The area represents soil-meliorative conditions with periodic flooding for rice cultivation on meadow-chernozem, chernozem, and meadow soils within the high Danube floodplain and adjacent supra-floodplain terrace. Over the last 23 years, it has been in a post-irrigation regime for agricultural use under crop rotation.

- DSS-6 Furmanivska – Chervoniarska Drainage System within the Kagul-Chinese Agromeliorative and Soil Reclamation District. Geochronologically autonomous landscape. Southern Chernozems of the warm phase, weakly dissected watershed plain. Irrigation with sulfate-sodium waters from the central part of the China Lake-Reservoir with a mineralization of 1.2-2.0 (up to 3.0) g/dm3. Over the last 27 years, irrigation has been irregular, and the mineralization of the irrigation water during these years is approximately 3-4 g/dm3. Since 2011, there has been no irrigation.

- DSS-7 Vinohradska – on the lands of Vinohradska Drainage System in the Bolhrad District within the Bolhrad-Kholsk Agromeliorative and Soil Reclamation District. Geochronologically autonomous landscape. Southern Chernozems of the warm phase, locally mycelial-carbonate. Dissected watershed plain. Irrigation with sulfate-sodium waters from the headwaters of Yalpug Lake-Reservoir (Tarakliy Canal) with a mineralization of 1.5-2.0, up to 2.5-3.0 g/dm3. Over the last 27 years, it has not been irrigated and is in the post-irrigation evolution regime.

- In the process of landscape and soil improvement control of agricultural lands in the given agro-melioration stations (AMC) of the Ministry of Agriculture (M3), soil profiles were established at the described key stationary monitoring sites. These profiles were excavated to a depth of up to 1.5-1.6 meters, or manual drilling was performed to a depth of 1.5-2.0 meters using boreholes repeated three times. Samples of soils and subsoil rocks were collected from the genetic horizons of the soil profiles for laboratory analytical research.

- In the chemical analysis laboratory of the Regional Soil Testing and Analysis Laboratory (PNDL-4) at the Odessa National University (ONU), the collected soil and rock samples underwent various analyses. The following parameters were determined: field moisture content, pH, particle size distribution (granulometry), structural-aggregate and microaggregate composition, salinity, and carbonation. Additionally, the content and fraction-group composition of humus, the capacity of adsorption, and the composition of exchangeable bases (cation exchange capacity) were analyzed. The laboratory also assessed the content of available plant forms of mineral nitrogen, phosphorus, and potassium in the samples.

- Furthermore, water samples were taken from the sites, and their pH, ionic composition, and mineralization were measured. The concentrations of NH4+ and NO3+ ions, as well as P2O5 and K2O, were also determined in the water samples.

- Research has shown that from the early years of irrigating black soils, new landscape-geochemical and soil-forming processes develop, some of which have negative (degradation) tendencies. Primarily, the water and salt regimes of black soils undergo significant changes, which largely determine the direction of physico-chemical processes and indicators of the agrophysical state of the soils. The most significant changes in the composition and properties of black soils, often of a degradational nature, occur when irrigating them with poor-quality waters of increased mineralization and sodium chemistry, provided that the initial soils are non-carbonated or leached.

- In contrast, when irrigating with irrigation-quality waters under conditions of soil carbonation and a non-deficient balance of humus and calcium, the changes in the state of black soils are much less pronounced. Significant changes in soil indicators occur mainly during the first 3-5 years of systematic irrigation, and in the subsequent 10-15 years, the rate of changes decreases.

- In summary, the study reveals that the irrigation of black soils leads to various changes in their properties and state, with the most substantial effects occurring when using poor-quality waters and non-carbonated or leached soils. However, when using high-quality irrigation waters and well-balanced soils, the impacts are less significant and tend to stabilize over time.

- With the cessation of irrigation in the black soils of the steppe zone of Ukraine for more than 20 years, processes of natural salinization by atmospheric waters are becoming more active. In the upper horizons of the soil profile, the content of both water-soluble and absorbed sodium decreases. However, in the lower horizons of black soils, especially those irrigated in previous years with highly mineralized sodium chemistry waters, the content of water-soluble sodium remains high, and the ratio of water-soluble $Ca^{2+}:Na^{+}$ is narrow (0.3-0.5, up to 0.7). The proportion of absorbed sodium also remains relatively high (3-5 times higher than in non-irrigated analogs) with a tendency to increase during dry periods.

- Black soils that were previously irrigated with low-mineralized waters reach the level of non-irrigated analogs in the root-containing layer of the soil (0-50 cm) in terms of the total content of water-soluble salts in approximately 10 years. As for the content of toxic salts, previously irrigated black soils reach the level of non-irrigated analogs in approximately 21 years. The Ca:Na ratio is still far from that of non-irrigated black soils, although there is an observed expansion of the ratio from 0.20-0.25 to 1-2.

- In the second meter of soil, there are no noticeable changes in the quantitative and qualitative composition of components in the water extract. Apparently, the current intensity of atmospheric moisture is insufficient for the faster migration of salts beyond the soil profile. Measures to promote the replenishment of calcium reserves in the soil are necessary to accelerate this process since the content of water-soluble forms of calcium in the soil remains practically unchanged.

- The agrophysical condition of the black soils (chernozems) significantly changes under irrigation, often leading to degradation. Parameters such as soil density, structure, and water-physical properties are affected, especially when using irrigation waters with increased mineralization of sodium or higher alkalinity. The cessation of irrigation in the past 20 years has resulted in some improvement in the agrophysical condition of the soils due to the leaching effects of atmospheric precipitation, reducing the impact of salinization and alkalinization.

- Currently, the agrophysical indicators of previously irrigated soils are practically similar to the non-irrigated chernozems in adjacent territories.

- The monitoring of humus status in the irrigated chernozems of the Odessa region since 1994 shows a tendency towards humus depletion in the region's soils, both in rainfed and irrigated conditions. This can be attributed to the dominance of cereal and sunflower crops in the crop structure without adequate application of organic and mineral fertilizers. However, in recent years, the use of advanced cultivation methods and crop residue management (mulching fields with the crop residues of previous crops) has shown a trend towards increasing humus content in both previously irrigated and rainfed chernozems of the Odessa region (by 0.04-0.37%).

- To further improve the humus status of the chernozems in the Odessa region, it is advisable to introduce crop rotations with alfalfa and perennial grasses and grass mixtures, and strictly prohibit the burning of straw and crop residues in the fields.

Recomendation

- Restoration of Traditional Irrigation in the region, mainly focusing on irrigation from the Danube and Dniester rivers, and partially from the Prut River and its lakes. Additionally, increasing the areas under intensive agricultural crops using drip irrigation technologies.
- Agroforestry measures (including protective and erosion-preventive forest strips) to combat soil degradation.
- Selection of agricultural crops considering climate change and the intensification of agrotechnologies, reviewing and adjusting traditional cultivation techniques based on local changes in weather and climate conditions – choice of crop varieties, planting dates, sowing rates, etc.
- Optimization of cropping patterns, considering natural-agricultural and agro-climatic zoning.
- Soil conservation measures to prevent various forms of soil degradation, mainly focusing on preventing humus depletion, erosion, and agrophysical and chemical-physical degradation.
- Development and adoption of a Ukrainian Law on Soil Conservation.
- Training of specialists through vocational and higher education institutions in the field of soil and agricultural conservation.

Thank you for attention!