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PROVIDING OF RESOURCE SAVING IN DANUBE RICE IRRIGATION SYSTEMS BASED ON REUSE OF DRAINAGE WATER AND WASTEWATER

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ABSTRACT

Questions of reuse of drainage water and wastewater of rice systems on the example of rice irrigation systems are determined. The technological scheme, which saves water and energy resources during the irrigation of crops in the rice system, is proposed. Calculations of economic efficiency of water circulation technology in the Danube rice irrigation systems (RIS) with drainage water and wastewater (DWW) dilution with fresh water in the ratio of 1 : 1 showed that the net profit will amount to UAH 26,266.5 per 1 ha, while the dilution in the ratio of 1 : 2 – to UAH 26,161.5 per 1 ha. Complementary net profit will accordingly amount to UAH 1,337.8 and 1,231.5 per 1 ha. The most perspective technique to use DWW in rice irrigation systems is their reuse with dilution with fresh water at a ratio of 1 : 1 or 1 : 2. This ratio corresponds to most indicators for which was done an evaluation of water that is supplied for irrigation. Also this ratio does not lead to deterioration of soil salt regime.

Key words: drainage water, wastewater, rice irrigation system, reuse

INTRODUCTION

The main requirements that apply to modern irrigated agriculture, including rice growing, are getting high, economically feasible agricultural yields, cost minimization, preservation of soil fertility and ecological condition of irrigated lands and adjacent areas (Tuong & Bhuiyan, 1999; Aleksashkin, 2007). The main resources used for irrigated agriculture, in comparison with dryland farming, are water and energy. Due to a noticeable deficit of these resources the problem of rational use of fresh water is becoming increasingly important. The reason is in the reduction of its supply and in the increase of the amount of slightly mineralized drainage water and wastewater (Lozovitskii & Musienko, 1987; Wu, Wu & Wu, 1995).

One of the most pressing problems that needs to be solved today by operational organizations, is the use of DWW in RIS (Vrochynskii & Makovskii, 1979; Aleksashkin, 2007). One hectare of rice cultivation uses 18,000–30,000 m^3 of water, about 50% of which is spent on filtering and discharges (Kovalov, Kozishkurt & Kozishkurt, 2004). In rice systems, every year, about 600 million m^3 of water is formed and discharged into the gulf of Black and Azov seas. For example, only in the Skadovsk district (Kherson region), up to 170 million m^3 of DWW are discharged into the gulf Dzharylhach annually, 110 million m^3 of which are with the mineralization up to 1,000 $mg \cdot dm^{-3}$ (Babenko & Duplyak, 1988). The annual intake from the Danube in the rice systems was 250 million m^3 in the early 1970s, and now it reaches 90 million m^3.

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Diversion of drainage discharges into water bodies leads to a partial change of their mineralization and, chemical contamination. The experience of most rice systems operating in Ukraine and abroad shows, that the average discharge is 30–70% of the quantity of water abstracted, supplied for irrigation. Mineralization of such water is usually low and ranges from 0.5 to 3–5 $g \cdot L^{-1}$. The presence of heavy metals' saults in DWW is the result of their contamination by decay products of herbicides, which are used in rice crop systems (Rokochinskiy, Volk, Pinchuk, Mendus & Koptyuk, 2017).

At the same time the use of DWW can be an important factor that can provide a significant increase in the area of irrigated land in southern Ukraine without increasing water intake from sources of irrigation, and a reduction of water consumption for irrigation of rice and related crops in rice systems. The purpose of the research is to study the possibility of using DWW for irrigation of rice and related crops in rice systems, their impact on soil processes, and to develop scientific foundations of controlled using DWW in rice systems for resources and environmental conservation.

MATERIAL AND METHODS

Methods of research included the identification of quantitative and qualitative indicators of drainage water and wastewater in RIS, the impact of technology of their use on the yield of rice and on soil processes.

To study the possibility of using DWW in the Danube rice system on irrigation, an evaluation of water quality that is supplied for irrigation by mixing fresh water with DWW in different proportions was conducted.

Such variants were estimated:

- possibility to use DWW without dilution;
- possibility to use DWW with their dilution with fresh water in a ratio of 1 : 2;
- possibility to use DWW with their dilution with fresh water in a ratio of 1 : 1;
- possibility to use DWW with their dilution with fresh water in a ratio of 2 : 1;
- irrigation with fresh water.

In the course of research were used the information base of source data for the object for the period 1966–2016.

RESULTS

Possibility of using DWW for rice irrigation

In the main rice-growing areas, considerable experience in the effective use of DWW in rice systems was gained (Dudchenko, Vozhehova & Shpak, 2008; Morozov, Kornberher & Dudchenko, 2010). The first studies related to the reuse of drainage water and wastewater in RIS for irrigation of rice and related crops on the Danube RIS were conducted in 1967–1980 on the Kiliya rice system (Skripchinskaia, 1980).

The research shows that for most rice systems the use of DWW for watering in the first years of their use is not possible. This can be explained by the mineralization of DWW and their unsatisfactory quality indicators because in the initial period of system operation, the desalination process is more intensive. After several years of correct operation of the rice system, the balance between the amount of salts that enter the soil balance and those which are allocated from DWW becomes relatively stable. During this period of operation DWW systems can be used for irrigation by dilution with fresh water in different proportions, or without such dilution.

When using DWW from rice fields it should be noted that the chemical composition of this water is formed by the dilution of fresh waste water with mineralized groundwater, which are drained by a collector-drainage network. Depending on the ratio of fresh water and DWW in water, which is submitted for irrigation, their mineralization and chemical composition can be altered. Therefore, before using waste water from rice fields for re-irrigation, it is necessary to study their chemical composition and how it changes in time. The first thing to look at while reusing DWW for irrigation of rice – is the presence of water-soluble salts, which are toxic to plants especially Na_2SO_4, NaCl.

Also the potential for the development of alkalinity of rice fields due to an excess amount of Na^+ ions, which are inserted with irrigation water, should be foreseen.

Nowadays, in meliorating practice, the following basic techniques of DWW use in rice systems for rice irrigation are known:

- reuse without flow dilution;
- reuse with flow dilution with irrigated water;
- reuse of DWW with supply in irrigation channels;
- partial reverse use of DWW.

Reuse without flow dilution consists in the fact that the drain from paddy fields, which is irrigated with fresh water, is supplied to the check situated below. Allowable DWW mineralization at such use of it should not exceed 1 $g \cdot L^{-1}$. It is necessary to exercise operational control of water mineralization, which is resupplied to irrigation, and to exercise the change of water salinity in the second check. Failure to comply with such requirements can cause lower yields of rice, because it has a weak salt resistance. In rice systems the drain can be used for irrigation without dilution with fresh water no more than 1–2 times. This technique is extended in the Krasnodar region.

Reuse with flow dilution with irrigated water consists in the fact that irrigation water to the first section is supplied fresh. Flow from it, diluted with fresh water, enters the second section, located below. Flow from the second section, also diluted, enters the third section etc. In conditions of rice systems in Ukraine, this method has no perspectives because of their design features that do not allow dilution of DWW in different parts of the system.

Reuse of DWW with supply in irrigation channels became widespread in the Kuban and the Crimea. In an irrigation system, points can be detected at which it is possible to pump water from reservoirs in rice irrigation channels. This method is effective when the rice system has achieved a high level of automation of farm and inter-farm water distribution. The salinity of water that is recycled and mixed with fresh water is controlled.

Partial reverse use of DWW is the most perspective in rice irrigation systems. This method consists in the fact that DWW are accumulated in storage ponds or water reservoirs with subsequent water supply at the head of the system in the inter-farm channel. After mixing in a channel with water that is taken from a river or reservoir, the flow is directed to irrigation. Such a system is equipped with automation devices of water regulation, control and communications. It enables to manage the process and ensures the most efficient use of DWW in rice systems.

When revolving cycles are growing, the mineralization of mixed irrigation water is increasing. Water mineralization does not have to exceed the threshold limit value. It is necessary to take out some DWW and then divert them in the water receiver. The advantage of this method, besides significant savings of water, is its environmental safety.

The research conducted by Taybe and Baranova (1983), and Melnikova (1985) has shown that while holding the runoff from rice systems in buffer tanks during the month, the destruction of herbicides to toxicological dangerous values occurs. Furthermore, pesticides that are carried into the soil environment with DWW are exposed to the processes that can reduce the content of toxicants in them. These processes include the effect of soil microorganisms and ferments, their adsorption with a colloidal complex of soils, pesticides distillation with water vapor and their transfer to a gaseous state, their collapse under the influence of ultraviolet radiation, filtration.

The quickness of destruction increases under the influence of solar radiation and artificial aeration. Afterwards, purification of sewage water is also carried out in interaction with aquatic vegetation ("bioplato" from reed, cattail), which is planted in basin-storages. Higher aquatic plants actively absorb pesticides and nutrients (Tuliakova, 1978; Skripchinskaia, 1980).

Possibility of using DWW for rice irrigation in Danube RIS

Conducted long-term studies in the Danube RIS (Kovalov et al., 2004) have shown that even under optimal irrigation, the norm per 1 ha of rice crops in the collector-drainage network gets 6,000–10,000 m^3 of water with salinity of less than 2 $g \cdot L^{-1}$. Increased salinity of DWW can be in the first flooding of rice and during harvest. Throughout all the irrigation periods, the mineralization of waste water does not exceed 3 $g \cdot L^{-1}$ (maximum) and ranges mostly from 0.6 to 1.7–1.8 $g \cdot L^{-1}$.

The research has shown that when creating water dams in sprinklers and household sewage the mineralization of DWW is 1.0–1.7 $g \cdot L^{-1}$. We had evaluated the suitability of water for irrigation, when diluting DWW and fresh river water with the help of methods of Budanov, Antipov–Karataev and Kader, Mozheiko–Vorotnik, and the U.S. Department of Agriculture (for sodium adsorption ratio SAR) (standard DSTU 2730-94). Variants of dilution in such ratios were considered: 1 : 2; 1 : 1 and 2 : 1 (Table 1).

The evaluation of irrigation water on the above mentioned methods has shown that at mineralization

Table 1. Chemical composition of DWW at its dilution with fresh water

Total mineralization [g·L^{-1}]	Ion concentration						Unit
	anion			cation			
	HCO_3	Cl	SO_4	Ca	Mg	Na + K	
Dilution 1 : 2							
0.70	4.10	4.62	1.58	3.45	3.25	3.6	mEq·L^{-1}
	0.244	0.161	0.076	0.069	0.039	0.083	g·L^{-1}
Dilution 1 : 1							
0.82	3.67	6.66	2.45	3.36	3.33	6.09	mEq·L^{-1}
	0.223	0.233	0.118	0.066	0.04	0.14	g·L^{-1}
Dilution 2 : 1							
0.99	3.92	8.68	3.13	3.61	4.14	7.98	mEq·L^{-1}
	0.239	0.304	0.3	0.144	0.099	0.184	g·L^{-1}

of DWW 1.35 g·L^{-1} and mineralization of the Danube water 0.29 g·L^{-1}, most suitable for irrigation, the irrigation water that is formed by dilution of DWW and fresh water is in the ratio from 1 : 1 to 1 : 2.

When backwaters in channels of the drainage network are not done, DWW mineralization may be increased to 3 g·L^{-1}. In this case water is most suitable for the irrigation of rice, which is formed by dilution of DWW and fresh water in a ratio of 1 : 3. The results of our research show that DWW diluted with fresh water can be used for irrigation, starting with the period when the cards are flooded again after rice comes up. We found that in such mode supply of DWW for irrigation on the research cards of the Krasnodar type (CKT) and card checks with drainage (CCD) that were placed on the system of channel P-2 of Kiliya rice system, stocks of salts were significantly decreasing in both soil and in groundwater (Table 2).

Table 2. Salt balance of DWW and card checks with drainage during irrigation with brackish water (on average over five years of research)

Elements of salt balance	Distance between drainages = 250 m			
	CCD		CKT	
	t·ha^{-1}	%	t·ha^{-1}	%
Stocks of salts in soil in April 1.2 m	41.49	41.22	38.42	38.55
Stocks of salts in the groundwater in a layer 1.8 m	48.58	48.28	51.04	51.19
Income of salts with irrigation water	9.09	9.04	8.80	8.83
Income of salts with fertilizers	1.46	1.46	1.43	1.43
Total salts in the balance layer (3 m) in April	100.62	100.0	99.69	100.0
Stocks of salts in soil in November 1.2 m	32.33	32.13	37.65	37.78
Stocks of salts in the groundwater in November in layer 1.8 m	34.82	34.60	37.76	37.88
Removal of salts with drainage water	27.76	27.59	21.90	21.96
Removal of salts with waste water	1.77	1.76	2.20	2.21
Removal of salts with harvest	1.25	1.25	1.15	1.15
Salt exchange with the lower horizons	2.69	2.67	–0.97	–0.98
Total salts in the balance layer (3 m) in November	100.62	100.0	99.69	100.0

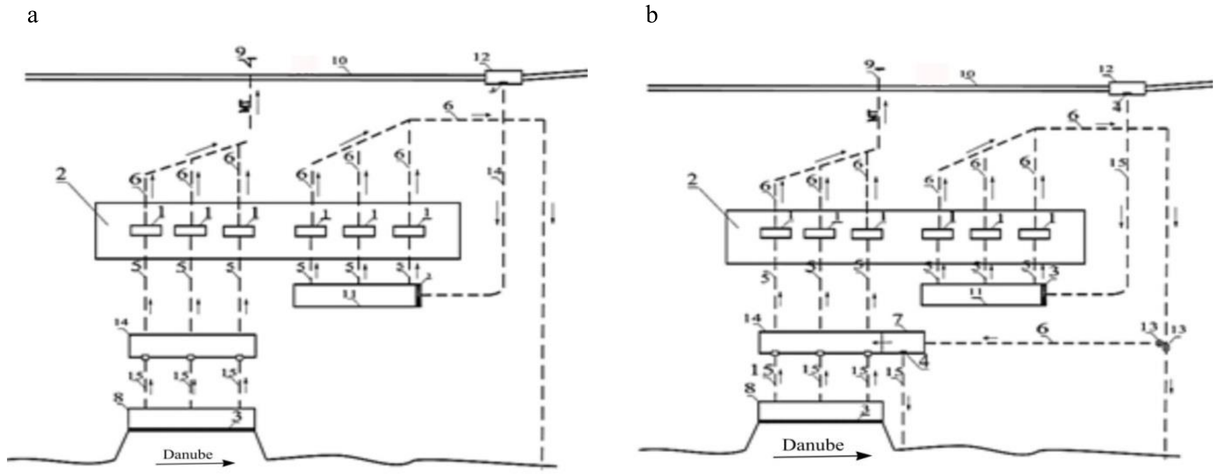

Fig. Schemes of water supply and drainage on Danube RIS: a – existing; b – proposed: 1 – pump, 2 – pumping station, 3 – sludge rake, 4 – sluice, 5 – suction pipe, 6 – penstock, 7 – pool to supply DWW for irrigation, 8 – fresh water intake, 9 – trunk pipeline that supplies water on irrigation, 10 – main spillway channel, 11 – DWW intake, 12 – pool for DWW storage, 13 – damper, 14 – forebay, 15 – low-pressure pipeline

The peculiarity of the Danube RIS is that they are situated in dicked areas. Pumping stations supply water for irrigation from the river Danube on this RIS. Also pumping stations remove DWW outside each of the rice systems into the Danube (Fig. a). Therefore, to supply water for irrigation and to remove DWW annually, considerable energy resources are expanded.

Reconstruction of water intake unit at the proposed scheme requires minimal costs related to the arrangement of the pool for dilution of DWW with fresh water from the Danube (7), two short dampers and a short area of penstock with length to 20 m.

Calculations of the economic efficiency of the water circulation technology in the Danube RIS with DWW dilution with fresh water at the ratio of 1 : 1 showed that the net profit will amount to UAH 26,266.5 per 1 ha, while the dilution at a ratio of 1 : 2 to UAH 26,161.5 per 1 ha. Complementary net profit will accordingly amount to UAH 1,337.8 and 1,231.5 per 1 ha.

CONCLUSIONS

Use DWW for rice irrigation, first of all, reduces pollution of irrigation sources by nutrients and residues of herbicides and insecticides that are not fully decomposed. Secondly, there is no need for pumping large quantities of fresh water for the irrigation of rice, which results in the saving of fresh water and electricity. Using DWW in Kiliya RIS can lead to energy savings up to 700,000 kWh. The most perspective technique to use DWW in rice irrigation systems is their reuse with dilution with fresh water at a ratio of 1 : 1 or 1 : 2. This ratio corresponds to most indicators for which an evaluation of water that is supplied for irrigation was performed. Also, this ratio is not likely to deteriorate the soil salt regime.

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OSZCZĘDZANIE ZASOBÓW W SYSTEMACH NAWADNIANIA PÓL RYŻOWYCH W DOLINIE DUNAJU WYNIKAJĄCE Z PONOWNEGO WYKORZYSTANIA WODY DRENAŻOWEJ I ŚCIEKÓW

STRESZCZENIE

W artykule omówiono kwestie dotyczące ponownego wykorzystania wody drenażowej i ścieków z systemów irygacyjnych na przykładzie systemów nawadniania pól ryżowych. Proponuje się schemat technologiczny, który umożliwia zaoszczędzenie wody i energii w procesie nawadniania upraw ryżu. Obliczenia efektywności ekonomicznej technologii cyrkulacji wody w systemach nawadniania pól ryżowych w dolinie Dunaju przy rozcieńczeniu wody drenażowej i ścieków wodą słodką w 1 : 1 wykazały, że zysk netto wyniesie 26 266,5 UAH na 1 ha, a przy rozcieńczeniu w 1 : 2 – 26 161,5 UAH na 1 ha. Dodatkowy zysk netto wyniesie odpowiednio 1337,8 i 1231,5 UAH na 1 ha. Najbardziej perspektywiczną techniką wykorzystania wody drenażowej i ścieków w systemach nawadniania pól ryżowych jest ich ponowne użycie przy zastosowaniu rozcieńczenia wodą słodką w 1 : 1 lub 1 : 2. Ten stosunek odpowiada większości wskaźników, dla których dokonano oceny wody dostarczanej do nawadniania. Ponadto taki stosunek nie prowadzi do zwiększenia zasolenia gleb.

Słowa kluczowe: woda drenażowa, ścieki, system nawadniania pól ryżowych, ponowne użycie