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Water resources management in rice irrigation systems and improvement of ecological situation in rice growing river basins

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Abstract. Water resources management in the rice irrigation systems in Kazakhstan as well as water conservation and its efficient use are associated with technological processes control factors such as irrigation efficiency, layout of rice bays and their terracing. Managing technological processes in rice systems is complex, since there are significant deviations in the technological parameters of rice systems from the optimal. Therefore, in order to properly manage these processes, it is necessary to know the impact, its direction, assess the results of these impacts and develop an appropriate scientific and information base. The paper considers the impact of rice bays layout quality and terrace on the water-salt regime of soils, rice productivity and irrigation rate. Also, it proposes improvements to parameters of rice systems, water conservation, environmental situation in areas of rice cultivation and water resources management in rice systems.

1. Introduction

Rice irrigation systems of Kazakhstan are located on terraces in basins of the Syrdarya, Ile and Karatal rivers on an area of 220 thousand hectares. The soils are alluvial-gray, takyr-like, lightly, medium and highly saline, the climate is sharply continental arid, and summers are hot with temperatures 30–45°C. Irrigation canals are half-excavation - half mounds, with drainage canals depth of 1.2-2.5 m. Rice is cultivated in rice bays, the area of which varies from 1.5 ha to 3.0 ha. The average deviation of the marks on the surface of the rice bay from the zero plane, according to the standards [4], during the construction of rice systems is ± 5 cm, after 50 years of operation is ± 10 ÷ 15 cm. Terraces of rice bays, the difference between the high and low marks of the bays according to the standards is allowed up to ± 30 cm, the actual value is ± 50 cm or more.

In many countries of South-east Asia, rice is cultivated on terraces; the difference in elevations of adjacent terraces is allowed up to 20 cm [5, 6, 7, 8, 9, 10]. On rice irrigation systems in Kazakhstan, the elevated terrace of rice bays leads to an excessive consumption of irrigation water, a decrease in rice yield, a deterioration in the ameliorative state of irrigated land and the socio-ecological state of the environment. For rice crop the irrigation norm of rice production is 25.6 thousand m^3/ha, with rice productivity 48 centners pen hectare, instead of the normative, 22.0 thousand m^3/ha and 55 centners

pen hectare, respectively. More than 26 thousand hectares of irrigated land of rice systems were excluded from agricultural use due to water logging and secondary salinization.
In this regard, the improvement of rice systems' parameters, water conservation and the development of water management technology for rice irrigation systems will save irrigation water, increase yield and profitability of rice production, as well as improve the environmental situation in rice growing river basins.

2. Materials and Methods

The field work was carried on the Kyzylorda and Akdala rice systems of the Syrdarya and Ile river basins, on the rice fields of the Shieli district of the Kyzylorda region and the Birlik agricultural farm of the Balkhash district, Almaty region. On rice bays, with the earth's surface examined squares of 20×20 m. On the studied areas of rice bays, the cost of irrigation water for rice cultivation, the salt regime of the soil and the yield of rice, were measured to determine the quality of planning work and terracing of rice bays using appropriate devices and equipment, weirs, GGI-300 evaporimeter, piezometers and salometer.
Pilot studies were carried out on the field with area of more than 100 hectares. The results of the study revealed socio-economic damage caused by non-compliance of rice irrigation systems' parameters with regulatory requirements, and allowed to provide some proposals on environmental improvement of river basins condition for rice cultivation.

3. Results and Discussion

Large losses of water on rice irrigation systems up to 50% are associated with filtering the water from irrigation channels, poor-quality of the surface of the rice bays planning and their terraces. According to the Kyzylorda "Vodkhoz" and "Balkhash Irrigation" enterprises' data, the efficiency of rice irrigation canals is 0.66, and the rice irrigation system is 0.63. The productivity coefficient of irrigation water consumption on the rice field does not exceed 0.42 of the water source intake rate. This situation leads to an exacerbation of irrigation water shortage, land removal from agricultural use, as well as loss of jobs and environmental degradation in the Syrdarya and Ile river basins. It is necessary to increase the efficiency of rice irrigation canals from 0.66 to the standard value of 0.80÷0.85. The measure is to save up to 508-677 million m3 of water on rice irrigation systems, to increase the irrigation area by 21,020–28,020 hectares and gross income by $23,879–32,141 and to provide additional 3,000 jobs. (Table 1)

Table 1. Increase in irrigation area and gross income on rice irrigation systems with increased efficiency of the irrigation network

Efficiency of rice irrigation network (channels)	Water intake from irrigation source, mln. m^3	Irrigation water supply	Irrigated area, thousand ha	Gross income, thousand dollars USA	Gross income growth	
					Thous., $	%
1	2	3	4	5	6	7
0.65	3385.0	2200.3	91121	94927.0	-	-
0.70	3385.0	2369.5	98121	102219.0	10239	11.1
0.70	3385.0	2538.7	105127	109518.0	17538	11.1
0.8	3385.0	2708.0	112138	115859.0	23879	26.0
0.85	3385.0	2877.2	119144.8	124121.2	32141.2	35.0

It is possible to reduce water losses in irrigation canals by using polyethylene materials. The channel bed is covered with a plastic film, the filtration of water from the channel is reduced and the channel efficiency can be increased up to 0.85÷0.87. Such experience is available in the Almaty region.

A major role in the formation of the agro-economic potential of the rice field is played by the planning of layout. When rice is cultivated, planning determines water, air, heat, salt, and biochemical soil regimes, which increase rice productivity and reduce the consumption of irrigation water for cultivation.

The quality of the layout or the smoothness of the surface of the rice bay is characterized by a set of deviations from its average mark. Deviations of the planned surface layout of the bay from the horizontal plane vary from year to year and depend on the quality of the capital and operational planning of the prior year. The absolute values of these deviations and the nature of distribution depend on a number of contingencies. In most cases, their sample distribution can be satisfactorily represented by the average value of their squared deviation, estimated according to the data of the sample itself, when the distribution of marks on the field is statistically subordinate to the normal law that describes the Gaussian distribution.

Statistical processing of the data [2] regarding the quality of rice bays surface planning by recording the ground surface parameters of the squares 20x20 m rice bay, shows that the probability of deviations up to ± 5cm constitutes 35%, and from ± 5 to ± 10cm constitutes 57.2%, deviations of more than ± 10cm constitute 6.8%, i.e. more than 60% of the bay area deviations exceeded the normative ± 5cm. With an average depth of flooding of the rice bay of 10 cm, the water layer is 20–25 cm at low elevations of the bay and 0–5 cm at high elevations.

Poor layout of the surface of rice bay is one of the main factors restraining the growth of rice productivity. Studies of the impact of planning/layout quality on the irrigation rate and rice yield showed that when the surface marks of the bay deviate up to ± 5 cm, rice yield is 7.3 t/ha, irrigation rate is 22.0 thousand m^3/ha, water consumption per ton of rice crop – 3,010 m^3. When deviation is ± 10 cm, rice yield decreases to 6.2 t/ha, water consumption per 1 ton of rice crop increases to 3,629 m^3, water overrun is 679 m^3/t. With an increase in the deviations of the surface of the rice bay up to ± 15 cm, rice yield decreases to 2.6 t/ha, water consumption increases to 8,846 m^3/t, water overrun to 5,836 m^3/t. (Table 2)

Table 2. Irrigation rate and rice yield at various marks of rice bay macrorelief

Indicators	Deviations of bay marks, cm		
	±5	±10	±15
Irrigation rate, thous. m^3/ha	22.0	22.5	23.0
Rice yield t/ha	7.3	6.2	2.6
Water consumption, m^3/t	3.010	3.629	8.846
Water overrun, m^3/t	-	619	5.836
Crop failure, t/ha	-	1.1	4.7

A one-way analysis of variance of the layout planning quality on rice yield confirmed the close relationship between the water layer on the rice bay and its yield: LSD_{05} = 20.4%, or LSD_{05} = 0.88 t/ha, F_{sur} = 284.4, F_{cr} = 2.77 [2]. If the marks deviate from the middle plane of the bay to ± 10 cm, the additional volume of water is 500 m^3/ha, up to ± 15 cm-1000 m^3/ha.

Economic calculations of rice cultivation efficiency on rice irrigation systems showed that if the rice bay surface marks deviate more than ± 5 cm, then each additional centimeter of poor-quality planning of the rice bay surface layout leads to $100 per ha loss of harvest of rice. When a deviation is up to ± 10 cm, the loss of harvest is $855 per ha, and a deviation of up to ± 15 cm results in loss of harvest $1,000 per ha. Water consumption for rice cultivation of a ton of rice increases by 619 m^3/t and 5,836 m^3/t, respectively.

The quality of rice bay layout and the earth's surface could be improved to ± 3-5 cm when planning a rice bay layout with a long-span leveler using a laser device. Such work is now carried out by separate cooperatives in small areas of the Kyzylorda region, where the average rice yield is 65–70 centners/ha, water consumption is 3,500 m^3 per 1 ton of rice grain.

Another reason for irrigation water unproductive use is secondary salinization of soils and a decrease in rice irrigation systems productivity due to terraces. The negative effect of terracing is that after

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flooding higher level rice crop bays adjacent bays enter into hydraulic interaction, so the filtration water from the higher bays move to lower, including salts, products of restoration processes [1].

In rice irrigation systems, active hydraulic interaction between adjacent bays occurs when a terrace is more than 30 cm. The hydraulic interaction width depends on the difference between adjacent bays (terrace) and constitutes 10÷20 m, when a terrace of bays is up to 40 cm, and 40÷60 m, when terraces of bays 40÷50 m. During rice cultivation, in the terrace section with a width of 40 m, the filtration rate of water from high bays is 140...200 m^3day/ha, then the filtration rate decreases to 80 m^3 day/ha. On adjacent lower bay with terrace of 50 cm and more groundwater closing with rice paddies water has been detected. A diffusive movement of salts from groundwater into the water layer of rice bays has been recorded.

The data processing of research materials showed that 45% of rice irrigation systems consist of the bays with a terrace of up to 30 cm, while 30-50 cm is 40%of bays and above 50 cm constitute 15% of bays.

Experimental studies have established that rice productivity on bays with a terrace of up to 30 cm is 6.7 t/ha, on higher bays with a positive terrace + 30 ÷ 50 cm it indicates 4.8 t/ha, on lower bays with a negative terrace -30÷-50 cm is 3.9 t/ha. On higher bays due to water filtration, nutrients are removed from the soil; the mineralization of water in bays increases on lower bays, which leads to a decrease in rice yield. Water consumption per 1 ton of rice crop with a terrace of up to 30 cm is 3,090 m^3/t, with increase of terrace elevation water consumption increases to 4,790 ... 5,540 m^3/t. (Table 3)

Table 3. Irrigation rates and rice yield on bays with different terraces

Indicators	Terraces of rice bays, sm.		
	30	+30÷50	-30÷-50
Irrigation rates, m^3/ha	20700	22992	21606
Rice yield, t/ha	6.7	4.8	3.9
Water consumption, m^3/t	3090	4790	5540
Wasted run-off, м^3/t m^3/t	-	1700	2450
LSD_{05}, %	19	18	12

The dispersion analysis of the rice bay terrace impact on rice yield, performed according to the method [2], shows that when rice bay terrace is more than 30 cm, the terrace effect on rice yield is very significant (LSD_{05} = 0.44t/ha).

Due to the poor layout and terraces of rice bays, rice productivity in different areas of the rice bay differs by 1.8... 2.2 t/ha. The dependence of rice productivity on the layout quality and terraces of the bay, according to the method is approximated by the following equations:

$$P.l = 7.34 + 0.39 \cdot h_i - 0.13 \cdot h_i^2, \ \ t/ha \tag{1}$$

$$P.tr = 6.1 - 0.24 \cdot h_{tr} + 0.02 \cdot h_{tr}^2, \ \ t/ha$$

where *P.l* is dependence of productivity on planning of layout and
P.t- dependence on terrace t/ha;
h_l– quality of bay surface layout, sm.;
h_{tr}– terrace of adjacent bays, m.

Correlation coefficient of dependencies is equal to 0.96 ±0.02.

The study of the salt regime and rice bays balance, depending on terraces, show that on higher bays with a terrace of + 30 ÷ 50 cm, the salt content in a 100 cm layer of soil is reduced by 25%, on lower bays with a terrace of-30 ÷ 50 cm by 6.1%. The salts supply with irrigation water is 23.8 ÷ 25.3 t/ha. The removal of salts from higher rice bays with groundwater flow is 23.7 t/ha, there is no groundwater outflow at lower bays; the water salinity in lower bays due to convective diffusion increases to critical limits of 2.5 g/l and there is a need for surface water discharges during the irrigation period. On lower bays with a negative terrace of -30 ÷ 50 cm, the salt content in 100 cm of the soil layer before the vegetation period is 68.1 t/ha, in autumn after rice harvesting is 64.0 t/ha. The salt removal by wastewater discharges is 5 6 t/ha and by drainage is 24.7 t/ha. (table 4)

Table 4. Salt regime and rice bays balance on experimental plots depending on their terrace, t/ha.

Balance sheet items	Terrace of rice bays, sm.		
	+30÷50	30	-30 ÷ -50
Salt content in spring before sowing rice	42.4	56.6	68.1
Saline with irrigation water	23.0	20.7	21.6
Total salt	65.4	77.3	89.7
Salt content in autumn after harvesting rice	31.8	49.9	64.0
Removal of salts by drainage	8.1	11.2	24.7
Removal of salts with wastewater	-	3.5	5.6
Removal of salts by filtration runoff and groundwater outflow	23.7	4.1	-
Total salt	64.6	78.7	94.3
Discrepancy, t/ha	-0.8	+1.4	+4.6
%	1.2	1.8	4.8

The reliability of the obtained results is confirmed by high values of the correlation (R = 0.72...0.95). The obtained results will help predict the rice yield and water consumption for its cultivation with rice bays terrace of above 30 cm.

The filtration of water from rice bays and the outflow of groundwater are determined by the salt regime of the rice bay water layer. On higher bays with a terrace of more than 30 cm, water filtration is 12 - 18 mm/day, the mineralization of the flooded layer of rice bay is 1.27...1.5 g/l, the lands are slightly saline with a salt content of 0.32%. On lower bays with a terrace of more than 30 cm the filtration of water in the bays is reduced to 2 mm/day, salinity of the water in the flooding layer of the bay increases to 2.5 g/l, saline lands with a salt content of more than 0.85%. The effect of the terrace of rice bays on filtration and salinity of rice bay water, rice productivity and salt regime of soils are presented in Figure 1.

On bays with a terrace of more than 30 cm, the there is a loss of rice yield for every 10 cm, on higher bays with a terrace + 30÷50 cm, the loss is $ 400 per ha, on lower bays with a terrace of -30÷-50 cm the loss is $589 per ha. Water consumption for rice cultivation increases by 4.790 m^3/t and 5,540 m^3/t. correspondingly.

The rice sowing area in Kazakhstan's rice irrigation systems is 98 thousand ha. The rice bays area with surface marks of more than ± 5 cm and a terrace level of more than 30 cm, with an average probability of P = 60%, is 58.5 thousand ha. Overrun of irrigation water on bays with elevated terraces and poor layout of rice bays is 176.4 million m^3 per year. More than 26 thousand hectares of rice paddies have been withdrawn from agriculture use due to water logging and secondary salinization, these are mainly lower bays with a terrace of 50 cm or more. Rice crop loss due to poor layout of rice bays and their terraces estimated at 211.6 thousand tons. Losses due to smaller rice harvest on rice irrigation systems, caused by poor-quality layout planning and elevated terraces, is estimated at 37.930 thousand USD per year.

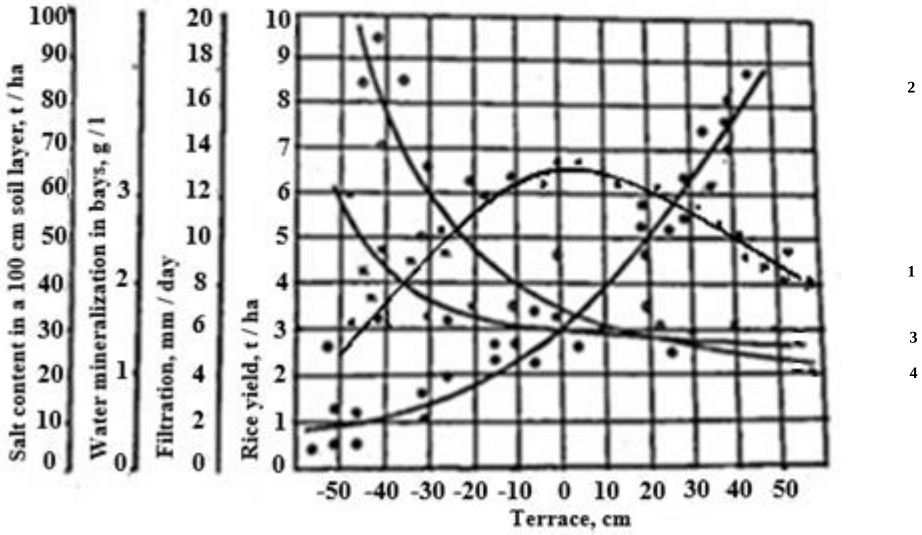

Figure 1. Impact of rice bays terrace on filtration and mineralization of water in the bays, rice yield, salt content in 100 cm soil layer: 1 - rice yield, t/ha, 2 - filtration, mm/day; 3 - water mineralization in bays, g/l ; 4 - salt content in a 100 cm soil layer, t/ha

The negative effect of rice bays terracing can be reduced by a cut-off drainage channel between higher and lower bays. Cut-off drainage channel with a depth of 0.8-1.2 m will intercept the flow of groundwater from higher to lower bays and improve the reclamation condition of lower bays, increase the rice yield by to 5.0 t/ha, reduce the cost of irrigation water by 1,500 cubic meters per 1 ton of rice yield. Such experience is available in some areas of rice systems in the Kyzylorda and Almaty regions.
Inconsistency between the rice irrigation systems' parameters with the normative requirements for land surface planning of rice bays ± 5 cm, and the rice bays terrace ± 30 cm reduces the economic indicators in rice-growing areas and deteriorates social situation, which is reflected in the environmental degradation of the Syrdarya, Ile and Karatal river basins. When the efficiency of rice irrigation canals is up to 0.80 and technological parameters of rice systems are brought to standard of ±5 cm and terrace layout level 30 cm, then the annual flow to the Syr Darya river will increase by more than 660 million m^3 of water per year.
Such volume of water in the Syr Darya river will contribute to filling the lake systems of the Aral sea delta. The area of lake systems in the upper delta will increase by 1.28 times, and the filling of lakes in the coastal systems will exceed the projected level by 30%.
The formation of active water exchange in the delta will allow to reverse the salinization of delta lakes which happened in the period from 1974 to 2012, when construction of temporary river waterworks disrupted the natural desalination effect of the river on lake systems [3].
The water resources management and water availability as a criterion of reliability of natural-economic systems of arid regions, including the Aral sea, is a set of parameters describing the degree and the probability of satisfaction of water needs in natural systems as a whole and by its components.
The water availability of natural and economic systems depends on the natural variability of water resources in space and time, on the other hand, on the Rules on Regulation and Distribution of Water resources in natural and economic systems.
The issue of water availability in the transboundary natural and economic system of the Syr Darya river basin is now very pressing. Taking into account the projected indicators of water consumption growth in the basin and the limited water resources conditions, sustainable water supply to the region is possible only through the implementation of a transboundary long-term development program based on the principles of economic effectiveness and environmental protection during the rice cultivation.

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4. Conclusion

The effectiveness of water resources management and water conservation in rice irrigation systems largely depends on the parameters of the micro and macro relief of the rice field. The smoothness of the surface of rice bays and their terraces determine the reclamation regime of soil, irrigation water costs for rice cultivation and its productivity and also ecological safety in river basins of rice cultivation.

1. Deviation of the rice bay surface from the average plane by ± 5 cm are allowed during the construction/planning; in the sections of soil cutting, the marks of the surface of the earth remained 5 cm higher relative to the sections of the embankment. During the rice systems use process, due to the expansion of the soil in the sections of cutting and planting the soil in the places of the embankment, the deviations of the rice bay surface from the average mark are ± 10-15 cm.

In the higher areas of the rice bay of +15 cm, the water layer in the irrigation period is 0-5 cm; in these areas, moisture-loving weeds as millet, cattail and others intensively grow. On lower sections of a rice bay with depth of 15 cm rice plants die due to a deep flooding layer of 25-30 cm. Rice yield on the rice bay area of 1.5-3.0 ha, depending on the macro relief of the earth's surface, differs by 1.8-2.2 t/ha. Rice yield loss constitutes 40% or more, and water consumption for rice cultivation increases by 10-15%. To reduce the consequences of these negative phenomena, it is necessary to carry out a capital layout planning of the rice bays with a laser-installed long-span leveler, which levels up the surface up to ± 3 cm.

Dispersion analysis has confirmed the close relationship between the water layer in the bay and rice yield, the yield of 7.3 t/ha was obtained in bay areas, where the surface layout is ± 5 cm. When the rice bay surface deviates from ± 5 cm to ± 10 cm rice yield loss is 1.1 t/ha, from ± 10 cm to ± 15 cm **-** 3.6 t/ha.

2. On rice irrigation systems, the allowed altitude of adjacent rice bays (terrace), according to standards is up to 30 cm, the actual adjacent rice bays exceeded 50 cm, sometimes up to 70 cm. On lower rice bays, due to the influx of groundwater from higher bays there is an accumulation of salts in the water of rice bays, soil and groundwater. The difference in rice productivity on higher and lower bays, with a terrace of 50 cm are 60% or more. At lower bays in the soil, restoration processes prevail with the release of hydrogen sulfide, from which rice shoots die. When a terrace of adjacent rice bays is less than 30 cm, there is no particular difference in the productivity of rice of adjacent rice bays.

To reduce the negative impact of rice bays terrace on rice productivity and irrigation water consumption for its cultivation, a shut-off drainage channel with a depth of 0.8-1.2 m is to be installed between adjacent bays with a terrace of 50 cm. Such technique is applied on the Kyzylorda rice system. The cut-off drainage channel intercepts the outflow of groundwater from higher bays to lower, as a result, the reclamation state of lower rice bays improves and productivity increases by 30-35%.

3. Increasing the efficiency of irrigation channels to 0.80, leveling the surface of rice bays to ± 3 cm and installing of shut-off drainage between adjacent rice bays with a terrace of 50 cm will preserve up to 660 million m^3 per year of water resources of the Kyzylorda rice irrigation system. The saved water can improve the ecological situation in the Aral Sea region, by replenishing the lake systems of the Syr Darya delta and releases to the Small Aral.

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