Influence of flooding regime on the dynamics of moisture and salt transport in the root layer

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Abstract. The results of the research showed that the soil flooding at different rates determines the dynamics of water absorption and various volumes of water infiltration. With increasing norms of soil flooding, absorption rate and the speed of infiltration water increase, thus reducing water contact with solid phase of the soil. Therefore, salts solubility in the pores of the soil and the amount of salts washed out from the roots soil strata decrease.
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Introduction

In the conditions of the Northern and Central Kazakhstan, one of the ways to increase the yield of fodder crops is the inundative irrigation, which ensures increased moisture reserves in the root layer. In case of inundative irrigation, unlike regular, soil is watered once a year, usually in the spring. Therefore inundative irrigation is more effective for growing field crops with short vegetation season [1, 2].

However, the negative factor that affects effectiveness of inundative irrigation is the fact that, same as with other types of irrigation, it leads to disruption of the natural balance and causes abrupt change in redistribution of the total water-soluble organo-mineral compounds formed naturally [3, 4]. These processes are related to the fact that in case of estuaries flooding water is lost through infiltration below the roots soil strata, groundwater level raises, and soil is salinified and alkalized [5, 6, 7]. As a result, soil and environmental conditions of irrigated ecosystems deteriorate, thus reducing soil productivity. In the conditions of the Central and the Northern Kazakhstan, where soils are prone to salinization, unsystematic use of soil has led to deterioration of its ameliorative properties and made it impossible to use these soils. Therefore, the indicators that determine effectiveness of the regime and technology of estuaries flooding are the volume of water use per unit of crop weight and changing salt regime in the root layer [8, 9]. Therefore, in development of their regime and the elements of estuaries irrigation it is necessary to set the volume of infiltration losses, the rate of water infiltration into the soil and the dynamics of salt reserves in the root layer.

Methods.

Research for establishing parameters of infiltration rate and the volume of infiltration loss and changes in the salt regime in the root layer was made in the dark chestnut soils of Central Kazakhstan, in the following regimes: 1. Soil was flooded every day with free filtrate flow rate of 500 m³/ha; 2. Same with norm of 1,000 m³/ha after 2 days; 3. Same with norm of 2,000 m³/ha after 4 days; 4. Same with norm of 4,000 m³/ha (reference).

Parameters of moisture and salt transfer in case of change in flooding regime were set using lysimeters with cross-sectional area of 300 cm² and height of 170 cm. During soil flooding period, absorption rate and volume of water filtration were determined along with mineralization of infiltration water in case of humidity change.

The influence of soil moisture regime on the processes of moisture and salt transfer in the roots soil strata was determined by measuring the volume of infiltration water, by defining its mineralization with measuring the flow rate of wash water at different stages of research. In the filtrate, the following group of salts and indicators of soil fertility were determined: CO_3^{2-}, HCO_3^-,Cl^-, SO_4^{2+}, Ca^{2+}, Mg^{2+}, Na^+, NO_2, NO_3, P_2O_5, K_2O, humus, pH [10]. The obtained ions were bound to each other into hypothetical salts.

To assess physico-chemical and nutritional characteristics of soils, the following was determined: humus, nitrogen, pH, total nitrogen and phosphorus, sodium in the flame, absorption capacity, aqueous extract, gypsum, carbon dioxide, mechanical composition, density of solid phase and density (bulk weight).

Research for establishing parameters of absorption and infiltration rate were made on dark chestnut soils of the Central Kazakhstan. Water-and-physical properties showed that studied soil had no explicit morphological indicators of hydromorphic property and alkalinity, and composed of heavy loam and light clay, which fact is confirmed by the analysis of soil mechanical composition. [9]

The results of chemical analysis show that salt reserves in the root layer are unevenly distributed in soil. Their minimum values of the top 0-50 cm layer are 0.360 % from the weight of absolutely dry soil (Table 1). Later, in the 0-100 cm layer, salt content is increased, and is 0.836% from the weight of absolutely dry soil.

Table 1. Initial salt reserves in flooded soils according to lysimeters

Horizons, cm	Anions				Cations			Total salts, %
	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	
0-50	N/A	0.039 / 0.63	0.018 / 0.51	0.198 / 4.125	0.024 / 1.20	0.015 / 1.19	0.066 / 2.875	0.360
0-100	N/A	0.031 / 0.51	0.041 / 1.17	0.507 / 10.563	0.082 / 4.10	0.015 / 1.19	0.160 / 6.953	0.836
0-150	N/A	0.032 / 0.52	0.066 / 1.88	0.434 / 9.042	0.062 / 3.10	0.019 / 1.54	0.156 / 6.802	0.769

Note: the denominator is the % from the weight of absolutely dry soil, and the numerator is the mg-eq per 100 g of soil

Main part

The results of the research showed that the soil flooding at different rates determines various volumes of water infiltration. At the same time, where soil was flooded with norms 500 and 1,000 m³/ha, after 1 flooding, there was water loss for infiltration. In the 1st case, where lysimeters were flooded every with a single norm of 500 m³/ha, the process of water infiltration occurred after the 4th flooding, i.e., when the size of total flooding norm was 2,000 m³/ha. At the same time, the volumes of infiltration losses amounted to 210 m³/ha (Table 2).

Table 2. Influence of flooding norms on the amount of infiltration loss

Cases	Single flooding norm, m³/ha	Periods between irrigations, days	Values of irrigation norms, m³/ha	Number of irrigations, times	Actual duration of flooding, days	Volumes of infiltration losses	
						m³/ha	in % from irrigation norm
1	500	1	2,000	4	0.130	210	10.5
2	1,000	2	2,000	2	0.358	370	18.5
3	2,000	4	2,000	1	1.062	540	27.0
4	4,000	-	4,000	1	2.625	2030	50.8

From the materials submitted, it follows that an increase in irrigation (flooding) norms leads to a growth of volumes of infiltration water. Therefore, in case 2, where flooding was made with norms to 1,000 m³/ha after 2 days, the process of infiltration occurred after the second watering. With that, the initial volumes of infiltration losses was more than in case 1, and amounted to 370 m³/ha or 18.5% of the irrigation norm. Comparative analysis of the volume of infiltration losses in cases 1 and 2 showed that they increased in case 2 by 160 m³/ha or more than 1.76 times. In the reference case (case 4), the maximum infiltration losses were obtained, which amounted to 2,030 m³/ha, or 50.8 % of the irrigation norm.

Analysis of the data shows that water supply for flooding in cycles with single norm of 500 m³/ha gives the greatest figures of moisture accumulation in the root layer due to reducing water movement rate in soil pores, thus increasing duration of water contact with skeletal content of soil, and is 1,790 m³/ha (Table 3).

Table 3. Values of moisture accumulation in the 0-150 cm soil layer and comparative values of infiltration losses.

case	Flooding norm, m³/ha	Periods between irrigations, days	Irrigation norm, m³/ha		Volumes of infiltration losses	
			gross	net	m³/ha	in % of case 4
1	500	1	2,000	1,790	210	10.5
2	1,000	2	2,000	1,630	370	18.5
3	2,000	4	2,000	1,460	540	27.0
4	4,000	-	4,000	1,970	2030	100

Changing soil flooding regime also affects the rate of water absorption and movement in soil pores. For example, in case where the single norm of soil flooding was 500 m³/ha, irrigation water impregnated into the soil within 12 minutes, or in 0.008 days. Therefore, the rate of irrigation water absorption for the first cycle was 6.02 m/day (Table 4). In the second cycle, the rate of water absorption is reduced. Therefore, in the second cycle, the duration of irrigation water absorption was more - 25 minutes or 0.017 days, and the absorption rate reduced to 2.92 m/day. The minimum values were obtained in the 4th cycle, where the duration of water absorption increased to 0.076 days, which is 9.5 times higher than in cycle 1. Therefore, the rate of water absorption decreased to 0.66 m/day.

Table 4. Duration and rate of water absorption by cycles of soil flooding

case	Flooding norm, m³/ha	Period between irrigations, days	Unit of measurement	Number of irrigations, times				Average weighted absorption rate
				1	2	3	4	
1	500	1	days	0.008	0.017	0.029	0.076	0.130
			m/day	6.02	2.92	1.71	0.66	1.540
2	1,000	2	days	0.136	0.222	-	-	0.358
			m/day	0.735	0.450	-	-	0.558
3	2,000	4	days	1.062	-	-	-	1.062
			m/day	0.188	-	-	-	0.188
4	4,000		days	2.625	-	-	-	2.625
			m/day	0.152	-	-	-	0.152

Similar pattern in changing duration and rate of irrigation water absorption in cycles takes place in case 2 as well. In this case, with the flooding norm of 1,000 m³/ha for cycle 1, water was absorbed by the soil within 0.136 days, and, therefore, the water absorption rate was 0.735 m/day. In cycle 2, duration of absorption increased and amounted to 0.222 days. As a result, the rate of absorption decreased and its average value was 0.45 m/day. In cases 3 and 4 soil was flooded with norms 2,000 and 4,000 m³/ha, therefore the duration of soaking was 1.062 and

2.625 per day, respectively, and absorption rate was 0.188 and 0.152 m/day.

The results of the research made it possible to state that cyclic water supply reduces absorption rate in soil. However, this method increases the number of irrigations and their duration. For example, in case 1, although actual duration of irrigation water absorption within 4 cycles was 0.130 days, the whole process took 4 days to comply with periods between irrigations.

In case 2, where the soil is flooded with the norm of 1,000 m^3/ha every other day, actual duration of the water absorption was 0.358 days. However, watering every other day set the duration of the watering process to 2 days. In case 3, soil flooding with norm of 2,000 m^3/ha in 1 cycle made it possible to finish irrigation in 1 day. In the reference case, soil flooding in 1 cycle with norm of 4,000 m^3/ha, due to decrease in absorption rate, resulted in an increase in the duration of irrigation. Therefore, in this case, the process of absorption and irrigation lasted for 2.625 days.

The results of irrigation water infiltration rate observations showed that flooding of soils in cycles determines the dynamics of water moments in soil pores. At the same time, in unsaturated soil, water movement has fading oscillatory nature. On the basis of research performed on different soil types in Kazakhstan it was found that the degree of instability of the hydraulic process dynamics is predetermined by the value of irrigation norms. Decreasing watering norms leads to decreasing the amplitude of water movement speed fluctuations in unsaturated soil strata [9].

One of the factors that determine soil fertility is the degree of salinity. Therefore, for the purpose of improving design and the technology of estuaries flooding, dynamics of soil salt regime should be determined in case of change in their flooding norms. This is due to the fact that the change in estuaries flooding regime determines the dynamics of water movement and therefore determines various salts solubility in the root layer. This is shown by the results of lysimetric research, where various amounts of washed out salts for the same irrigation norms were obtained.

For example, with the same irrigation norms, the largest number of salts washed out with infiltration water was obtained in case where the soil flooding was performed every day with the norm of 500 m^3/ha. In this case with gross irrigation norm of 4,000 m^3/ha, the amount of washed out salt was 13.32 t/ha, and the average salinity of washed out salts was 7.745 g/l (Table 5).

Table 5. Influence of flooding norms on the amount of washed out salt

Cases	Single flooding norm, m^3/ha	Period between irrigations, days	Number of irrigations	Irrigation norm, m^3/ha		Volume of infiltration water, m^3/ha	Volume of washed salts	
				gross	net		g/l	t/ha
1	500	1	8	4,000	2,280	1,720	7.745	13.32
2	1,000	2	4	4,000	2,160	1,840	6.729	12.38
3	2,000	4	2	4,000	2,010	1,990	5.974	11.89
4	4,000	-	1	4,000	1,970	2,030	5.441	11.04

From the materials presented it follows that with the increase in flooding norm, intensity of soil salt discharge decreases. Therefore, in case 2, the average mineralization of washed out salts was 6.729 g/l, and the amount of washed out salts was 12.38 t/ha. Comparative analysis shows that in the second case salt discharge of soils decreased by 7.6 %, as compares to case 1. In case 3 salt discharge of soils keeps reducing, and so does the amount of washed out salts, while the average mineralization of washed salts was 5.974 g/l. The minimum salt discharge was obtained in reference case 4, where the average mineralization of washed out salts was 5.441 g/l. In this reference case, the amount of washed out salts is by 20.6% less than in case 1, by 12.1% less than in case 2, and by 7.7% less than in case 3.

Influence of water movement rate in soil pores on the intensity of salt discharge of soils is also confirmed by the ionic composition of the washed out salts (Table 6). For example, the average mineralization washed out chloride ions, with increase in flooding norms, reduces, and in case 1 is 1.971 g/l, and in case 4 - 1.256 g/l.

Table 6. The ionic composition of washed out salts

Cases	Unit of measurement	Anions				Cations			Total salts
		CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	
1	g/l	0.023	0.845	1.971	2.351	0.164	0.195	2.196	7.745
	t/ha	0.04	1.45	3.39	4.04	0.28	0.34	3.78	13.32
2	g/l	0.021	0.751	1.682	2.064	0.146	0.174	1.891	6.729
	t/ha	0.04	1.38	3.10	3.80	0.27	0.63	6.95	12.38
3	g/l	0.029	0.742	1.459	1.774	0.106	0.134	1.730	5.974
	t/ha	0.06	1.48	2.90	3.53	0.21	0.27	3.44	11.89
4	g/l	0.031	0.738	1.256	1.640	0.101	0.132	1.543	5.441
	t/ha	0.06	1.50	2.55	7.16	0.43	0.55	6.98	11.04

Similar dynamics during change of estuaries flooding norms was obtained for SO_4^{2-} ions. The maximum average mineralization of this ion was also obtained in case 1, where the average mineralization of washed out SO_4^{2-} was 2.351 g/l, amount of washing off was 4.04 t/ha. With an increase in estuaries flooding norms there was a decrease in its intensity and, accordingly, in the amount of washing out. Therefore, the minimum amount of washed SO_4^{2-} was obtained in the reference case.

The cation composition of washed out salts shows that in all cases cations Na^+ prevailed. Thus, this cation amounts to 28 to 30% of the salts. Cations Ca^{2+}, compared to other cations, have the lowest content indexes, and its content in the composition of washed out salts varies between 1.8% and 2.2% of the total amount of salts.

Among the washed out anions and cations, Cl, SO_4^{2-} and Na^+ prevail, indicating that the infiltration water washes out mostly non-toxic salts. This is confirmed by the qualitative composition of the salts washed out from the roots soil strata (Table 7).

Table 7. Qualitative composition of washed out salts

Cases	Non-toxic		Toxic						Total salts
	$Ca(HCO_3)_2$	$CaSO_4$	Na_2CO_3	$NaHCO_3$	$MgSO_4$	Na_2SO_4	NaCl	Total	
1	0.665 / 1.14	-	0.041 / 0.07	0.477 / 0.82	0.958 / 1.65	2.349 / 4.04	3.255 / 5.60	7.080 / 12.18	7.745 / 13.32
2	0.591 / 1.09	-	0.037 / 0.07	0.421 / 0.78	0.848 / 1.56	2.055 / 3.78	2.777 / 5.11	6.138 / 11.29	6.729 / 12.38
3	0.429 / 0.85	-	0.051 / 0.10	0.576 / 1.15	0.655 / 1.30	1.850 / 3.68	2.413 / 4.81	5.545 / 11.04	5.974 / 11.89
4	0.409 / 0.83	-	0.054 / 0.11	0.592 / 1.20	0.644 / 1.31	1.664 / 3.38	2.078 / 4.21	5.032 / 10.21	5.441 / 11.04

Note: the numerator is average mineralization, g/l; the denominator is t/ha.

Analysis of the data shows that in all cases non-toxic salts are found in washed out salts only in the form of calcium bicarbonates - $Ca(HCO_3)_2$. With that, the amount of washed out salts does not exceed 1.14 t/ha or 8.8 % of the amount of salts.

The content of toxic washed out salts in the cases varies between 91.2% and 92.9% of the total of salts. Toxic salts in the filtrate are found in the form of Na_2CO_3, $NaHCO_3$, $MgSO_4$, Na_2SO_4 and NaCl. Analysis of changes in toxic salts content in case of changing of estuaries flooding norms shows that sodium chlorides are washed pit most of all. Depending on the flooding regime, content of this salt varies between 38.1% and 42.0% of the total of salts. Next to sodium chloride, sodium sulfate Na_2SO_4 prevails, the amount of which depending on the flooding varies between 30.6% and 31 %.

The intensity and amount of washing out for Na_2CO_3 and $NaHCO_3$ also depend on the flooding norms, and, accordingly, to salts concentration in the soil solution. With a decrease in the value of single flooding norms and an increase in salts solubility, soda formation intensifies in the root layer. Therefore, the minimum content of these salts were obtained during cyclic soil flooding.

Conclusions

Thus, water supply to the estuaries in cycles helps to reduce infiltration water loss, increases the duration of contact with water and soil skeleton, and, respectively, increases the amount of salts washed out from the root layer. Therefore, in the conditions of water scarcity, improvement of water supply and soil desalinization in the estuaries of the Central and the Northern Kazakhstan can be achieved by improving the design of existing estuaries. For the existing deep-water estuaries, their flooding norm is 10,000-15,000 m³/ha. Transition to shallow estuaries makes it possible to reduce the norm of irrigation to 2,000-4,000 m³/ha. Shallow estuaries ensure cyclic flooding with small norms.

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