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Assessment of water-salt regime of irrigation system

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ABSTRACT

The main source of water for irrigation of agricultural crops in the Shieli area is the Syrdarya River in the Central Asia. The main part of the river water intake originates in the Tomenaryk town through the trunk channel New Shieli. Through this channel, agricultural land in Akmaya, Kodamanov, Begezhanov, Zhuantobe, Bestam and other farms is irrigated. Through the Kamystyayak channel, farms in villages Bidaykol and Jahaev are irrigated. Through pipes located in irrigated areas, groundwater level and salinity indicator were identified. The ameliorative condition of the irrigated land in farms was considered unsatisfactory only in certain farming lands, due to their lowland and highland location, a change was noticed in soil mechanical composition. Soil salinity index depends on mineralization of irrigation water and groundwater. In the autumn 2019, a rapid drop of the groundwater level has been observed. This was caused by the fact that the water level of the Syrdarya River was lower, and the groundwater level in irrigated land dropped rapidly. To optimize this issue, the article presents the current state of irrigated lands in the lower reaches of the Syrdarya River in Kyzylorda Province, as well as the results of work on regulation of water-salt regime. So, research work was conducted on 71.15 ha of agricultural land Bidaikol (former Giant), belonging to the Zhanakorgan-Shieli irrigation massif. According to the results of the research, it was optimal to provide the fields with water through a specially prepared biofield planted with dense reed plants. It was proved that purified irrigation water from the biofield is effective for irrigation of fodder crops. In addition, the reed itself is widely used in the republic as a fodder crop. Young reeds collected in August (at this time the reeds will be soft and the leaves green) are finely chopped and stored with a press using a special technology. Due to the growing importance of winter fodder, the price of reeds has increased significantly in the southern and southwestern regions of the country. For instance, in 2019 the price of 1 press of cane fluctuated between 650 and 850 tenge. In addition, in spring 2019 there was a shortage of fodder in the western regions (Aktau, Mangistau). Taking into account all these problems that the work done in the article is very relevant and more effective.

Keywords: Salinity, Experimental plot, Agriculture, Checks, Flushing, Drainage.
Article type: Research Article.

INTRODUCTION

The primary cause of man-made salinization is the salt brought in with irrigation water. All irrigation water derived from rivers or groundwater, however 'sweet', contains salts that remain behind in the soil after the water has evaporated (Khasanova *et al*. 2019). For instance, assuming irrigation water with a low salt concentration of 0.3 g L^{-1} (equal to 0.3 kg m^{-3}, corresponding to an electric conductivity, EC, of about 0.5 dS m^{-1}) and a modest annual supply of irrigation water of 10,000 m^3 ha^{-1} (almost 3 mm day^{-1}) brings 3,000 kg ha^{-1} salt each year. In the

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absence of sufficient natural drainage (as in waterlogged soils) and without a proper leaching and drainage program to remove salts, this would lead in the long run to a high soil salinity and reduced crop yields in the long run (Hoffman & Durnford 1999). Much of the water used in irrigation has a higher salt content than in this example, which is compounded by that fact that many irrigation projects use a far greater annual supply of water. Sugar cane, for instance, needs about 20,000 m^3 ha^{-1} water per year. As a result, irrigated areas often receive more than 3,000 kg ha^{-1} salt per year and some receive as much as 10,000 kg ha^{-1} $year^{-1}$ (Doneen 1954). Normally, the salinization of agricultural land affects a considerable area of irrigation projects, on the order of 20 to 30%. When the agriculture in such a fraction of the land is abandoned, a new salt and water balance is attained, a new equilibrium is reached, and the situation becomes stable (Pitman & Läuchli 2002). In the Shieli district of Kyzyl-Orda region in 2019, the area of irrigated land was 31,118 ha. Out of that area, the area of irrigated land with utility systems was 25,801 ha, and the total area of fields was 22,736 ha (Anuarbekov *et al*. 2015). In terms of weather conditions, the Shieli district is characterized by hot summers and very cold winters. The favorable period for crop planting continues from April to mid-October. The hottest month is July; the coldest months are January and February. Within the area, except for some years, rainfalls are very rare. Atmospheric precipitation occurs in winter and spring. According to the data from the Shieli Weather Stations, the amount of precipitation in 2019 was 164.7 mm. The highest temperature was +27 ℃ while the lowest temperature 4.8 ℃; the average temperature +13.3 ℃ (Anuarbekov *et al*. 2018; Zhaparkulova *et al*. 2019). In the area, the water supply into the channels starts on the third week of April. Water supply to the fields starts in May and continues until August 25. Hydrogeological and ameliorative conditions of the irrigated lands are a complex system, i.e., they depend on soil salinity, water supplied to crops and the level of ground water (Shomantaev 2001).

MATERIALS AND METHODS

Soil salinity was measured as the salt concentration of the soil solution in terms of g L^{-1} or electric conductivity (EC) in dS m^{-1}. The relation between these two units was about 5/3: y g/l => 5y/3 dS/m. Seawater may have a salt concentration of 30 g L^{-1} (3%) and an EC of 50 dS/m. The standard for the determination of soil salinity is from an extract of a saturated paste of the soil, and the EC is then written as ECe. The extract is obtained by centrifugation. The salinity can more easily be measured, without centrifugation, in a 2:1 or 5:1 water: soil mixture (in terms of g water per g dry soil) than from a saturated paste. The relation between ECe and EC 2:1 is about 4, hence: ECe = 4 EC 1:2 (ILRI 2003). Soils are considered saline when the ECe > 4. When 4 < ECe < 8, the soil is called moderately saline, when 8 < ECe < 16 it is called saline, and when ECe > 16 severely saline (Richards 1954). Chemical composition of soil and water were determined in the laboratory; i.e., content of pH, total nitrogen (N), ammonium and nitrate nitrogen, sulphates (SO_4), chlorides (Cl) were determined by the method developed by YY Lurye and AI Rybnikova. However, contents of calcium (Ca) and magnesium (Mg) were determined using a complex-metric method. Contents of potassium (K), sodium (Na) were determined using a photometer, and air chemical humidity (chemical oxygen demand) was determined using the dichromate method. Soil chemical composition was determined twice a year, in spring and in autumn. Samples of soil at a depth of 60 cm were taken every 10 cm, and further to the depth of 100 cm, each 20 cm in 3 repetitions. Soil moisture was determined by the drilling and the thermostatic method. The norm of salt flushing was determined by the equation of VR Volobuyev:

$$M = \alpha \log\left(\frac{S_n}{S_0}\right)10000 \quad \textbf{(1)}$$

Sn is the amount of salts in 1 meter thick layer of soil (%);

S0 is restricted (limited) value of salt in 1 meter thick layer of soil (%);

a is the amount of water for flushing 1 ton of salts from soil. In terms of Kyzyl-Orda, according to the data from Zh. Baymanov, this figure is equal to $\alpha = 0.50$.

where: M is the norm of flushing (m^3 ha^{-1});
In conditions of the experiment, flushing was performed twice, 2300 m^3 of feed water each. The period between the first and second flushing was 5 days. The mount of salt collected in the soil is found by multiplying irrigation norms by the amount of salt ingress with water. In addition, the amount of salt withdrawn from the soil is determined by multiplying the volume of sewage water by its salinity.
In our experimental plot with the area of one check of 0.5 ha, amount of water supplied to the check was 1150 m^3 ha^{-1}, i.e., 1150000 liters of water should be supplied. Water-transmitting capability of the channel was 100 L s^{-1}.

$$t = \frac{1150000}{100} = \frac{11500\,sec}{60sec} = \frac{192\,\text{min}}{60\,\text{min}} = 3.2 \text{ hours} \qquad \textbf{(2)}$$

Then on 1 limit-flushing operation we spent 3.2 hours. In addition, the entire plot of 71.15 ha was washed out for 19, or 454.4 hours/24 days. This was one-time flushing. Water was released again every 5 days. The entire flushing process took 38 days (Ritzema 2006).
Sensitive crops lost their vigor already in moderately saline soils, most crops were negatively affected by (moderately) saline soils, and only salinity resistant crops thrived in severely saline soils (Blaylock 1994).

RESULTS
The experiments were made on 71.15 ha of Bidaykol agricultural land plots in Shieli region (Fig. 1). We called these plots B-71-8, i.e., here B stands for Bidaykol, 71 is the area of the irrigated plot and 8 stands for the number of the well in the irrigated plot.

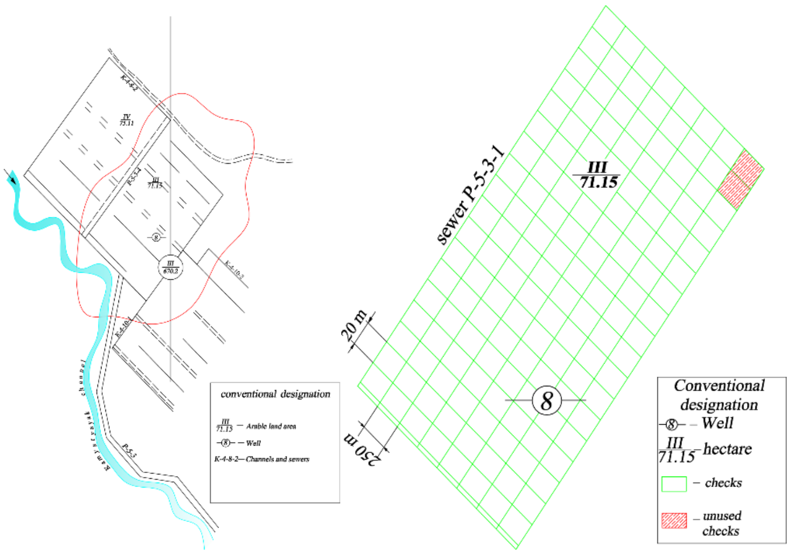

Fig. 1. Hydrogeological and a meliorative conditions of experimental plot.
B-71-8 (the Bidaykol irrigated farm field).

Crops in locations where we carried out the experiments are located in the southwestern part of the Bidaykol irrigated cultivation farm. Well No. 8 is the closest to it. 49 ha of alfalfa and 22 ha of silage maize were planted on our experimental arable farm field. Drainage is the primary method of controlling soil salinity. The system should permit a small fraction of the irrigation water (about 10 to 20 %, the drainage or leaching fraction) to be drained and discharged out of the irrigation project (van Hoorn 2006). About 24 sewage pipes were installed the farm. Since they were installed in 1980, at the moment only 18 of them were operating. Using the data obtained from these pipes and our own data from water studies, we determined land salinity indicators. While in March 2019 the groundwater level was 2.64 m, its salinity was 3.52 g L^{-1}; in June, the groundwater level was 1.40 m, its salinity was in the range of 2.55 g L^{-1}, and in October, the groundwater level was 2.38 m, its salinity was 3.00 g L^{-1}. In irrigated agriculture, cereal and forage crops were mainly cultivated. Here, the main crop, rice, as well as grain maize, early crops, several kinds of alfalfa, etc., were cultivated (Fig. 2). Also, the discharged water was driven via drainage P-5-3-1. Fig. 3 shows the total amount of salts in the soil plot used for the experiments.

Table 1. Data on experimental land plot B-71-8 in terms of water intake, water supply to crops during the vegetation period (2019) and precipitation in the area according to the data from the Shieli Weather Station (2018-2019).

Indicators	Experimental plot B-71-8
Water intake (planned; mln.m^3)	1.11
Water supply to fields (planed; mln.m^3)	1.01
Water intake (actual; mln.m^3)	0.90
Water supply to fields (actual; mln.m^3)	0.68
Amount of water sent to the drainage (mln.m^3)	0.18
Performance	0.82
Precipitation (2019, average per year; mm)	164.7

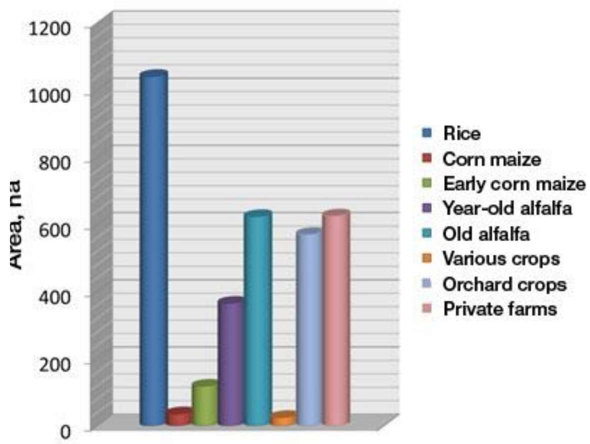

Fig. 2. Main crops cultivated at Bidaykol agricultural farms.

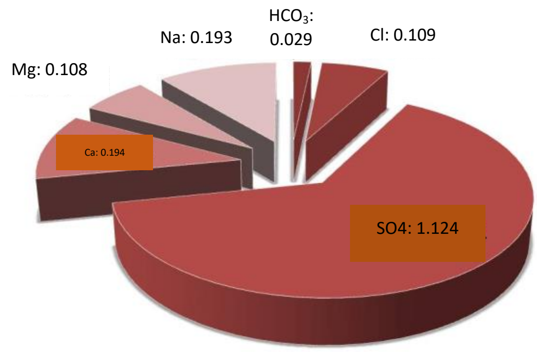

Fig. 3. Indicators of salts in the soil of experimental plot B-71-8.

In order to improve the salt regime for years 2017-2019, soil flushing was undertaken for two consecutive years. At the beginning, in the plot of 71.15 ha, the initial amount of salts in the soil was 1.757% by weight of dry soil. Flushing was made jointly with Bidaykol economic institution. Soil was flushed, and salt-and-water regimes were studied on land plot of 71.15 ha. In many cases a seasonal average water table depth of 0.6 to 0.8 m was deep enough. This means that the water table may occasionally be less than 0.6 m (say 0.2 m just after an irrigation or a rain storm). This automatically implies that, in other occasions, the water table will be deeper than 0.8 m (say 1.2 m). The fluctuation of the water table helps in the breathing function of the soil while the expulsion of carbon dioxide (CO_2) produced by the plant roots and the inhalation of fresh oxygen (O_2) is promoted.

The establishing of a not too deep water table offers the additional advantage that excessive field irrigation is discouraged, as the crop yield would be negatively affected by the resulting elevated water table, and irrigation water may be saved. The statements made above on the optimum depth of the water table are very general, because in some instances the required water table may be still shallower than indicated (for example in rice paddies), while in other instances it must be considerably deeper (for example in some orchards). The establishment of the optimum depth of the water table is in the realm of agricultural drainage criteria (ILRI 2003).

The aim was the establishing of water-salt regimes of cultivated land under optimal conditions. To achieve this goal, the following works were performed:

definition (by laboratory methods) of soil chemical composition before the experiment;

definition of the amount of water taken for irrigation of crops, and its salinity;

definition of the amount of drainage water and its salinity;

crop yield from irrigated fields;

Chemical composition of soil and water was defined in a specially-equipped laboratory of the Regional Committee for Environment Protection and Biological Resources.

On 71.15 ha of agricultural land, checks were prepared in advance. The area of each check was 250 × 20 m^2. The total number of checks was 144, including two checks that were considered worthless lands.

Before flushing with this amount of water, the following work was performed:

- grading the land plot;
- preparation of a protective belts at the height of 0.25 m;
- preparation of trapezoidal Thompson drainage system in order to normalize the checks' water supplying channel system;
- definition of common indicators of salt in one meter thick layer of soil before flushing, in March, 2018;
- in accordance with results of laboratory analysis, the overall content of salts in the one meter thick layer of soil amounted to 1.757% by weight of dry soil.

General flushing results are presented in Table 2.

Table 2. Indicators of flushing norms for 2 years at experimental plot B-71-8 of the Bidaykol agricultural farm (%).

№	Indicators	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	Amount of salts
1	2	3	4	5	6	7	8	9	10
	Year 2018								
1	Initial amount of salts in soil (data obtained in March. 2018)	0.00	0.029 0.48	0.109 3.08	1.124 23.42	0.194 9.70	0.108 8.90	0.193 8.38	1.757
2	Amount of salts after the first flushing norm (flushing started on March 13 and ended on March 31)	0.00	0.014 0.23	0.083 2.37	0.831 17.31	0.159 7.95	0.082 6.78	0.163 7.09	1.332
3	Amount of salts after the second flushing norm (flushing started on April 5 and ended on April 24)	0.00	0.008 0.13	0.059 1.68	0.526 10.96	0.124 6.20	0.058 4.79	0.131 5.69	0.906
	Year 2019								
1	Initial amount of salts in soil (data obtained in March. 2019)	0.00	0.015 0.25	0.086 2.46	0.822 17.12	0.152 7.60	0.084 6.94	0.169 7.35	1.328
2	Amount of salts after the first flushing norm (flushing started on March 15 and ended on April 3)	0.00	0.007 0.11	0.052 1.48	0.513 10.69	0.105 5.25	0.053 4.38	0.128 5.56	0.858
3	Amount of salts after the second flushing norm (flushing started on April 8 and ended on April 27)	0.00	0.003 0.05	0.027 0.77	0.206 4.29	0.063 3.15	0.022 1.82	0.101 4.39	0.422
	Difference (+/-)	0.00	0.026	0.082	0.918	0.131	0.086	0.092	1.335

Fig. 4 shows the table image as a histogram.

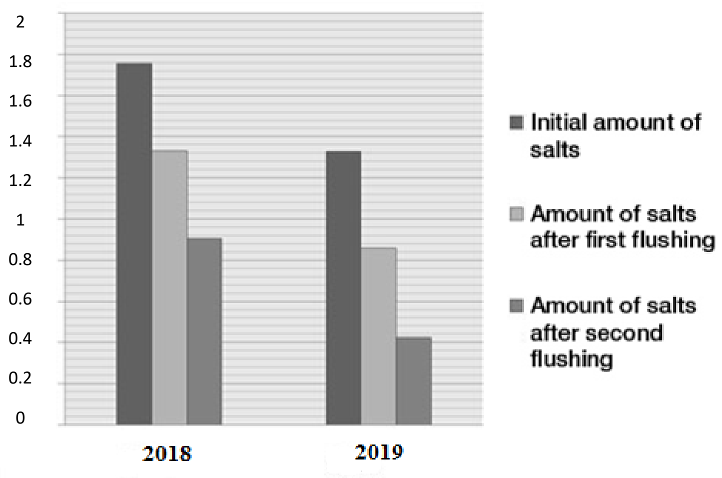

Fig. 4. Dynamics of plot flushing norms.

As shown in Table 2 and Fig. 4, the initial amount of salts in the experimental plot B-71-8 of the Bidaykol agricultural farm where the study was performed was 1.757% by weight of dry soil. With these indicators, it was hard to get a good harvest from this area. The salt content indicator beneficial for plants should be within the range of 0.3 to 0.5%. Within 2 years, thanks to normal flushing, salts content reduced from 1.757% to 0.422%. Yield of alfalfa and silage maize grew. According to the data for the autumn 2011, from the 2600 ha of alfalfa in the Shieli region (while the total area of the region is 24.081 ha), 10 kg ha^{-1} yield was obtained. In the calculation of this

index, the 49 ha of alfalfa of our experimental plot amounted to the yield of 0.19 ton ha^{-1}, and for silage maize, the area of 172 ha amounted to the harvest of 65.8 c ha^{-1} in calculating this indicator. A total of 22 ha of silage maize in our experimental plot amounted to the yield of 8.41 ton ha^{-1}. These figures changed after flushing several times. While in year 2018 from our experimental plot with 49 ha of alfalfa (at that time the total planting acreage was 31118 ha) we obtained the yield of 0.28 ton ha^{-1}, and from 22 ha of silage maize we obtained the harvest of 14.36 c ha^{-1}; in 2019 the yield amounted accordingly to 0.33 ton ha^{-1} and 17.75 ton ha^{-1}.
These data made it possible for us to calculate the water-and-salt regime of the considered irrigated plot.

DISCUSSION

Elements of the water balance

The volume of water supplied to the experimental plot B-71-8 was 0.67 m^3 sec^{-1}; and expenditures for water absorption from the main channels were calculated in the amount of water received.

$F_k =$ amount of water (water intake) × efficiency (1-efficiency channels) m^3/sec;

$$F_k = 0.85x(1 \quad 0.82) = 0.15 \text{ mln. } m^3$$

1. According to Soyuzgiproris data, incoming and outgoing ground water have been calculated as equal.
2. According to weather station data, for years 2012-2013 the amount of atmospheric moisture amounted to 164.7 mm.
3. $$164.7\text{mm } x10x71.15\, ha = \frac{117184.05}{1000000} = 0.12 \text{ } m^3/\text{sec}$$
4. According to the data of the Hydrogeology Institute, the amount ∑Z of evaporation is equal to known indicator of evaporation of plants and water movement:

F_{total}: total area of 71.15 ha;
F_{al}: total area of alfalfa 49 ha;
F_{sm}: total area of silage maize of 22 ha;
F_{rfl}: area of rain-fed lands of 0.15 ha;
Z_{al}: evaporation of water from the surface of lands occupied by 12 ha of alfalfa;
Z_{sm}: evaporation of water from the 0.80 ha of silage maize;
Z_{rfl}: evaporation of water from rain-fed lands of 0.08 ha (Table 3).

$$\sum Z = \frac{49x12 + 22x0.80 + 0.15x0.08}{71.15} = \frac{605.612}{71.15} = 0.085 \text{ thousand } m^3\, ha^{-1}$$

Table 3. Water balance

Elements of water balance	1 ha (thousand m³)	Total mln. m³
1	2	3
Incoming		
Supplied water		0.67
Atmospheric moisture		0.12
Water absorbed by MK		0.15
Total		0.94
Consumption		
Amount of evaporation	0.085	0.25
Drainage water		0.18
Vertical absorption		0.30

Total	0.73
Balance	**0.21**

5. Drainage-and-drainage water amounted to 0.18 mln.m³
6. In rice fields, vertical water absorption according to the institute is 0.30 thousand m³ ha^{-1}.

Raising the groundwater on all irrigated, rain-fed cultivated fields in the water balance:

$$dH = \frac{0.21}{71.15x0.17} = 0.02\,\text{m}$$

Elements of salt balance:

1. Changes of soil salinity is determined by the following formula:

$$\sum Z = \left(S_{суар} + S_{сі} + S_{атм}\right) - \left(S_{кол} + S_{нім}\right) \qquad \textbf{(3)}$$

$S_{орош}$ is the amount of salts coming with the waters of the channel 0.67 × 1.30 = 0.87 thousand tons;

$S_{впит}$ is the amount of salts coming with absorbed water 0.15 × 1.30 = 0.19 thousand tons;

$S_{атм}$ is the amount of salts coming with atmospheric moisture 0.12 × 0.85 = 0.10 thousand tons;

$S_{кол}$ is the amount of salts coming through the drainage waters 0.18 × 3,88 = 0.70 thousand tons;

$S_{урож}$ is the amount of salts brought out with crop yield of 0.41 thousand tons (Table 4).

Table 4. Salt balance

Elements of salt balance	Amounts of salts (thousand tons)
1	2
Incoming	
With irrigation water	0.87
With assimilated water	0.19
With atmospheric moisture	0.10
Total	1.16
Consumption	
With drainage water	0.70
With yield	0.41
Total	1.11
Balance	**0.05**

According to these two tables, the amount of water coming to the experimental plot was 0.94 mln.m³, and the water flow was 0.73 mln.m³. The difference of 0.21 mln.m³ of water is lost. In case of 1.16 thousand tons of salt coming to soil, and 1.11 thousand tons of salt outgoing, the difference of 0.05 thousand tons of salt remains in the soil. The majority of the computer models available for water and solute transport in the soil (e.g. SWAP, DrainMod-S, UnSatChem, and Hydrus) are based on Richard's differential equation for the movement of water in unsaturated soil in combination with Fick's differential convection–diffusion equation for advection and dispersion of salts (SWAP 2003; DBAE 2022; AWESRU 2022; PCPPE 2022). The models require input of soil characteristics like the relations between variable unsaturated soil moisture content, water tension, water retention curve, unsaturated hydraulic conductivity, dispersivity and diffusivity. These relations vary to a great extent from place to place and from time to time and are not easy to measure. Further, the models are difficult to calibrate under farmer's field conditions because the soil salinity here is spatially very variable. The models use short time steps and need at least a daily, if not an hourly, data base of hydrological phenomena. Altogether this makes model application to a fairly large project the job of a team of specialists with ample facilities. Simpler models, like SaltMod, based on monthly or seasonal water and soil balances and an empirical capillary rise function, are also available. They are useful for long-term salinity predictions in relation to irrigation and drainage practices. LeachMod, using the SaltMod principles, helps in analyzing leaching experiments in which the soil salinity was monitored in various root zone layers while the model will optimize the value of the leaching efficiency of each layer so that a fit is obtained of observed with simulated soil salinity values. Spatial variations owing to variations in topography can be simulated and predicted using salinity cum groundwater models, like SahysMod. In irrigated lands with scarce water resources suffering from drainage (high water table) and soil salinity problems, strip cropping is sometimes practiced with strips of land where every other strip is irrigated while the strips in between are left permanently fallow (ILRI 2000).

CONCLUSIONS

Drainage water from large rice fields Kyzylkum, Tugisken and Kyzylorda on the left bank flows in the direction of the Syrdarya River towards the Aral Sea. Combination of natural and anthropogenic factors leads to significant increase of river water mineralization, concentration of toxic salts in it, appearance of anthropogenic pollution in the form of toxic chemicals in water. According to the latest data, 2.5-3.5 million tons of salt from irrigation areas enter the Syr Darya water per year. The average annual value of mineralization is 1.5-1.7 g L^{-1} in Tumenaryk and 1.7-1.8 g L^{-1} in Kazaly, the maximum value in some periods is 2.0 g L^{-1} in Tumenaryk and 3.0 g L^{-1} in Kazaly. At all values of mineralization the type of ionic composition is sulfate-sodium.

Therefore, in the current situation, in order to create a sustainable water-salt regime in irrigated areas, assess the ameliorative condition of irrigated lands and solve problems arising from the environmental and social situation in the region, we still recommend the following integrated research works:

- annual comprehensive control of mineralization of Syr Darya water;
- agrochemical survey of saline areas (photo survey);
- creation of cartogram of saline soils;
- study water-physical composition of soil and rate of salt leaching into soil;
- revision and reconstruction of arable land structure;
- improvement of water allocation and water use management;
- introduction of advanced technologies, technical and constructive solutions;
- treatment and reuse of drainage water in agriculture;
- treatment of wastewater and its utilization in agriculture.

In addition, to further improve water-salt regime, it is recommended to supply water to the field through biofield. Its area should not be less than 2% of irrigated land area.

So, at present, in order to further improve the water-and-salt regime of soil, it should be flushed every year. Flushing is the most effective in autumn and early spring. During these seasons, water level in Syrdarya River is higher, while the amount of salt is lower.

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