



THE PARADIGM OF ECOLOGICAL SUSTAINABILITY OF KALMYKIA MELIORATIVE RICE AGRO-LANDSCAPES

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ABSTRACT

Evaluation of the rice meliorative systems operating mode of Kalmykia Republic is presented in the article and shows the criteria of negative processes, such as secondary salinity and salinization of soils, for which the value of hydroecological risk is unacceptable and is within 0.42 and 0.69 respectively. Complex of measures, tools, chemical and biological melioration methods is offered to maintain the melioration situation at an acceptable level, such as reconstruction of the collector drainage system; improving of conditions for removal of waste and drainage waters from the site territory; observance of the washing irrigation regime of soils with the removal of salts with drainage water; regular capital and current planning of map's checking with bringing the level of the surface to a constant level with variation $\pm 3...5$ cm from zero plane; improving the structure of rice crop rotation; carrying out activities for chemical melioration saline and saltmarsh soils. The results of rice agro-landscapes design research years are presented with the inclusion of improving meliorative crops to the crop rotation, which are capable to increase bio-energy productivity of agro-ecosystem and to provide a positive humus balance, an increasing in rice soil's fertility, an agricultural landscapes productivity in case of minimum energy costs. Ecological efficiency of resource-saving technologies of dry upland crops cultivation is proved, due to the formation of high harvests without watering with the use of after-rice residual moisture reserves (280...300 mm). Melioration impact ecological efficiency of crops-ameliorants in rice rotation is improvement of water-physical properties (total porosity and aeration porosity increase by 5...7% and 9...12% respectively); reduction of the composition density by 7.52...10.3%; the increase in the number of the most agronomically valuable soil aggregates (0.25...10 mm) by 9.95...16.04%; the increase in the structure coefficient from 0.9 to 1.7...1.9; reduction of the groundwater level and territory flooding risk by 35%. The plowing of plant residues (from 4.0 to 14.8 t/ hectare) allows to increase the humus content by 15...18%, improve the phytosanitary condition of rice fields (by 42...75%), increase the rice grain yield by 0.39...1.13 t/hectare.

Keywords: geo-ecological risk, groundwater, meliorative agro-landscape, productivity, rice rotation, salinization, secondary salinity, soil.

INTRODUCTION

Water scarcity is a global problem, particularly in arid and semi-arid areas. This fact should be taken into account in water resources management (Pejic *et al.*, 2014). Ecologically safe operation of agro-landscapes including rice meliorative, is provided through a balanced impact of natural and anthropogenic factors to the system "climate-soil-water-animal world-plant".

Conceptual model of Earth natural biogeochemical system as an object of impact, developed by scientists of Volgograd branch of the All-Russian Institute of Hydraulic Engineering and Land Reclamation A.N. Kostyakov is based on the concept of open systems that have the stability, self-regulation, translational dynamic equilibrium (Kostyakov, 1960; Parfenova and Reshetkina, 1995; Kireycheva *et al.*, 2008). In this connection, the ecological balance basic principles of meliorative agricultural landscapes are (Kostyakov, 1960; Kovda, 1984; Aydarov and Golovanov, 1986; Parfenova and Reshetkina, 1995; Dedova and Adyaev, 2007; Udzhuhu *et al.*, 2007; Kireycheva *et al.*, 2008; Borodychev *et al.*, 2012; Ovchinnikov *et al.*, 2016a): the fullest and the most efficient use of water and land

resources; adaptive use of all types of land reclamation taking into account of soil and climatic conditions and certain territory hydrological conditions; the use of water-saving and soil-protective technologies of crop cultivation; phytomelioration of natural grasslands; counteraction to soil salinity and water-logging in the meliorated lands; socio-economic interest of agricultural producers in maintaining of productive potential of the used lands. Development of unfavorable anaerobic conditions, groundwater increase, change of natural automorphic conditions by hydromorphic occurs in the conditions of Kalmykia, on rice irrigation systems as a result of heavy irrigation norms in case of poor state of the drainage system. The processes of soils depletion in carbon and exchangeable calcium, losses of organic matter, compression, lump's structure formation are widely developed. The density of the composition may increase to 1.5 kg/m³ or more, the processes of soil reversible cementation develop quite often (Dedova and Adyaev, 2007; Borodychev *et al.*, 2011; Borodychev *et al.*, 2012).

Carrying out the whole complex of adaptive agricultural meliorative measures that satisfy to the requirements of ecological safety is necessary for



ecologically safe land use in the rice reclamation systems of Kalmykia Republic. In this connection, research aim is rice agricultural meliorative landscapes studying and development of ecologically safe bases of its operation.

MATERIALS AND METHODS

Kalmykia rice crop rotations are located in the area of Sarpinsky watering irrigation system's (SWIS) and Kalmyk-Astrakhan rice irrigation system's (KARIS) activity on saline light-chestnut soils and brown semi-desert soils in a complex with saltmarsh, which are characterized by the following agro-physical and agrochemical properties: the density of plow layer is 1.37 g/cm³ (1.55 g/cm³ in metre); the soil belongs to the silty coarse-silty loams and clays according to the granulometric composition, because the fractions of dust and silt dominate in it (particles with a diameter of 0.05-0.01 or less 0.01 mm); the humus content in the layer 0-20 cm - is 1.1-1.4%, in the layer 20-40 cm - is 0.75-1.03%; the content of mobile phosphorus and exchange potassium is medium; salinization of the plow layer is medium; chemism varies in section from chloride-sulphate to sulphate-chloride. Underground water is at a depth of 1.8-2.2 m. It's mineralization is 2.9-3.4 g/l.

Soil meliorative and engineering hydrogeological conditions (especially at SWIS) are complicated and difficult. These systems were designed and is operated mainly as rice systems. The water supply is carried out by water intake from the Volga River in the Volgograd and Astrakhan regions, and it is associated with significant costs of electricity for water supply. The main source of water for irrigation is the Volga River (the water mineralization is 0.2...0.6 g/l). The Volga River is

worsening in all indicators and especially in the chemistry of the mineralization during its transportation because all the channels for water supply is located in the ground in the territory with a big content of water-soluble salts in the soil structure. It transforms from the sulfate-hydrocarbonate-calcium to chloride-sulphate-sodium-calcium type, since the chlorine content reaches 15% of the total amount of ions already in the on-farm irrigators. Mineralization of water increases to 0.7...1.0 g/l and corresponds to the II class of quality in on-farm irrigators (Borodychev *et al.*, 2015; Ovchinnikov *et al.*, 2015, 2016b).

Reclamation fund amounts to 43700 hectares, including regular - 19761 hectares, initiative - 4764 hectares, liman - 19175 hectares in the area of activity of SWIS and KARIS. Supply of drainage is less than 15%. Up to 30% of these lands had initially poor reclamation condition in these systems due to the high proportion of saltmarsh and natural salinization of the root-containing layer. Analysis of the current ecological situation in rice irrigation systems of the steppe part of the Sarpinskaya lowland shows, that 43% (3459 hectares) of the total area of irrigated land is in satisfactory meliorative condition, and 57% (4572 hectares) is in unsatisfactory condition due to secondary salinity and salinization (Dedova *et al.*, 2011).

This territory is located in the semi-desert zone of the Kalmykia Republic for natural zonation (Narodetskaya *et al.*, 1974). The main feature of semi-desert zone climate is its sharp continentality - summer is hot and very dry, winter is not with much snow, sometimes with severe frosts. Continentality of the climate increases from West to East (Table-1).

Table-1. Description of Sarpinsky lowland natural climatic conditions.

Parameters	Semi-desert zone
Area, million hectares	1.73
Average temperature, °C: the most cold month the most warm month	-8, -9 24.7...25.5
The sum of $t > 10^{\circ}\text{C}$	3329...3523
The frost-free period, days	143...190
The rainfall (P), mm/year	243...278
Number of days with dry wind, days	100...119
The rainfall for the period IV-IX, mm	147...174
Evaporation (E_0), mm/year	1100...1180
Full-year coefficient of hydration ($K_y = P / E_0$)	0.22...0.26
The level of aridity Coefficient of aridity	highly arid 0.16...0.30

It was studied the influence of plant-phytomeliorants (alfalfa sowing, sarepta mustard, spring rape, sunflower) on soil fertility of rice fields to improve the meliorative state and soil fertility of rice fields. The interaction of natural and anthropogenic factors

influencing the ecological state was taken into account in the studies, it was determined the reaction of plant-phytomeliorants on the studied agricultural practices and their combinations, improving the productivity of



agrocenoses and reducing the negative consequences of rice irrigation systems of Kalmykia Republic.

The basis of scientific research includes classical teachings about soil, soil-forming processes, soil fertility, salinity processes of V.V. Dokuchaev, V.I. Vernadskiy, V.R. Viljams, A.N. Kostyakov, V.A. Kovda, B.G. Rozanov. The ecological state of irrigated soils has been studied according to the methods, developed by Volgograd branch of the All-Russian Institute of Hydraulic Engineering and Land Reclamation A.N. Kostyakov and Volga research Institute of hydraulic engineering and land reclamation (Kireycheva et al., 2008; Ovchinnikov et al., 2015). There were used the definitions given in the works of N.F. Glazovskiy, N.I. Koronkevich, N.I. Parfenova, N.M. Reshetnikova, L.V. Kireycheva, S.D. Isaeva to describe the ecological condition of irrigated lands. There were used Fund materials of the soil analytical laboratory of Kalmyk branch of the All-Russian Institute of Hydraulic Engineering and Land Reclamation A.N. Kostyakov, materials of Kalmykia Republic meliorative inventories for 1983...2014 during carrying out the ecological assessment of the rice meliorative systems functioning regime of Sarpinsky lowland. Processing of experimental results was carried out by methods of correlation, regressive, dispersion analyses by B.A.

Dospekhov's technique, with the program "STATISTICA 6.0" and Microsoft Excel XP spreadsheets.

RESULTS AND DISCUSSIONS

Long-term cultivation of rice in difficult soil and climatic conditions of Sarpinsky lowland has led to the mass development of soil degradation processes and a sharp decrease in fertility indicators due to the absence of meliorative measures complex to restore and improve the ecological situation. The processes of water-logging, salinity and salinization of soils have intensified due to the deterioration of the technical condition of the irrigation and collector-waste system.

We have carried out the evaluation of the rice meliorative systems operation mode of Kalmykia Republic according to acceptable geo-ecological risk of major negative consequences developing (5-15%). The magnitude of geo-ecological risk may be estimated as percentage ratio of the area (ΔS) with negative processes to the total reclamation system area and adjacent lands (S) (Table-2).

$$P_0^m = \frac{\Delta S}{S} \times 100\%.$$

Table-2. Operation mode evaluation of rice meliorative system.

The main negative natural-meliorative processes	The magnitude of acceptable geo-ecological risk	Meliorative system's operation mode
Flooding of the territory	0.10	0.24 (ecologically acceptable)
Secondary salinity of soils	0.05	0.42 (ecologically unacceptable)
Salinization of soils	0.15	0.69 (ecologically unacceptable)
Loss of humus in the soil	0.05	0.13 (ecologically acceptable)

Geo-ecological risk is characterized by the following standard levels:

- insignificant geo-ecological risk is the minimum level of acceptable risk, which is at the level of fluctuations in the level of risk formation or is determined as 1% of the maximum permissible geo-ecological risk;
- acceptable geo-ecological risk is the risk that is justified from the point of view of ecological, economic, social and other problems;
- the maximum permissible geo-ecological risk is the maximum level of acceptable risk, which may be determined by the complex of negative processes and should not be exceeded.

Analysis of the Sarpinsky rice meliorative system operating mode of the Kalmykia Republic shows, that the value of geo-ecological risk is unacceptable in such criteria as secondary salinity and salinization of soils, and is in the limits of 0.42 and 0.69 respectively.

Meliorative situation in SWIS is caused by flooding of the territory by raising the level of groundwater to 1.25...2.2 m, this criterion is characterized

as ecologically acceptable (0.24). Reduction of humus horizon power and humus reserves occurs in rice agro-landscapes and is associated with insufficient supply of soil with plant residues. So, the loss of humus is 0.13 in rice soils in terms of geo-ecological risk.

Thus, anthropogenic pressure is manifested through change and worsening of an agricultural landscape component, in particular, soil properties. Other degradation processes are manifested, such as increased groundwater salinity, decarbonization of soil, along with described negative natural meliorative processes. All this has a negative impact on growth and development of cultural and natural plants and reduces its biological productivity.

According to the materials of irrigation systems meliorative cadastre (Kalmyk irrigation meliorative party), more than 3.0 thousand hectares of rice checks on the lands of the liman area were removed from agricultural turnover because of unsatisfactory melioration situation. Unfortunately, the designs of rice areas do not allow to create the desired mode. Insufficient depth and rarefaction of the existing collector drainage system do not provide timely removal of waste and drainage water. The sharp



rise of mineralized groundwater to unacceptable values occurred in the early years of operation as a result of water supply required for rice cultivation.

The presence of layers of «chocolate» clays contributed to the formation of water layer at a depth of 1.0...1.5 m in the aggregate with poor performance of collector drainage system and its constant overflow and led to the fact that the salts which dissolved in irrigation water and filtered through the soil layer are not taken out and remain in the same place. Only the top 0...40 cm layer of soil is relatively exposed to the washing under rice and deeper lying layers have a high degree of salinity.

It should be noted that intensive processes of secondary salinity and salinization and salinity manifestation of salts on the soil surface occur during cultivation of crops with periodic watering, under conditions of liman landscape, as a result of capillary rise and evaporation, and almost all area of checks become unsuitable for cultivation of agricultural crops.

The maintenance of meliorative situation in an ecologically acceptable level requires a complex of measures with the use of means and methods of chemical and biological melioration:

- Reconstruction of collector drainage system: deepening of waste drainage economic channels, or map's channels to 2.5...3.0 m and building of additional drains and effluents as an aim to reduce the distance between drains to 100...200 m; equipment of an additional temporary waste drainage channels with a depth of 0.6...1.0 m inside of map checks across the irrigators-effluents (with output from them) at a distance of 50...100 m from each other; equipment of peripheral single-flange channels also with output to irrigators-effluents; equipment of cavernous drainage in maps-checks with the depth of cavities location by 0.4...0.6 m, distance between them of 1...3 m and location across of irrigators-effluents and with output of cavities to them.
- Improving of conditions for removal of waste and drainage waters from the area territory: provision of quick water removal from map-checks during the period of rice harvesting and forced relative water consumption (not less than 50 l/s per 1 hectare) during the watering of associated crops with the use of mobile pumping stations, irrigation machine of "PPA-400" type and mobile siphon devices.

- Enforcement of washing watering soil mode with drainage water.
- Carrying out of regular capital and current planning of map-checks with bringing the surface to a constant level with variations of $\pm 3...5$ from the zero plane.
- Improvement of the crop rotation structure: integration of the so-called "upland" crops to the rice crop rotations, which are capable to form high big yields without watering using residual moisture reserves after the rice cultivation (280...300 mm) and are having phytomeliorative properties; cultivation of salt-resistant plants (halophytes), belonging to the family Chenopodiaceae: *Salicornia europaea*, *Suaeda altissima*, *Halocnemum strobilaceum*, *Chenopodium glaucum*, *Atriplex macrantha* *Atriplex calotheca*. Halophytes grow on soils with a salt content of 1.8...3.0% and are characterized by a clear adaptability to different types of salinity. These plants form up to 15 tons per hectare of absolutely dry phytomass. In this case, it is removed of 5.5...6.5 t/hectare from the soil (Rudneva, 2000).
- Carrying out activities for chemical melioration of saline and saltmarsh soils and for improving their structural state (in case of washing mode): a mandatory technique is a deep meliorative loosening of the soil to a depth of 0.8...1.0 m using devices such as RG-0.8, RG-1.2 and etc. which ensure the improvement of structure and filtration capacity of the soil, in case of ensuring the reduction of groundwater level to 2.5...3.0 m; it is necessary to bring phosphogypsum of gypsum in a dose of 4...6 t/hectare during the soil surface cultivation for rice crops, after the planning carrying out; it is necessary to carry out slitting and cavity-making of surface to a depth of 0.4...0.5 m with the distance of 0.5...1.2 m between slits and cavities with bringing them to the central irrigator-effluent of map-check in case of perennial crops cultivation of rice crop rotation.

There were included crops-ameliorants to the rice crop rotation, improving bio-energetic productivity of agro-ecosystem and providing the positive humus balance, increasing of rice soils fertility and agro-landscapes productivity with minimal energetical costs during the design of rice agro-landscapes (Figure-1).

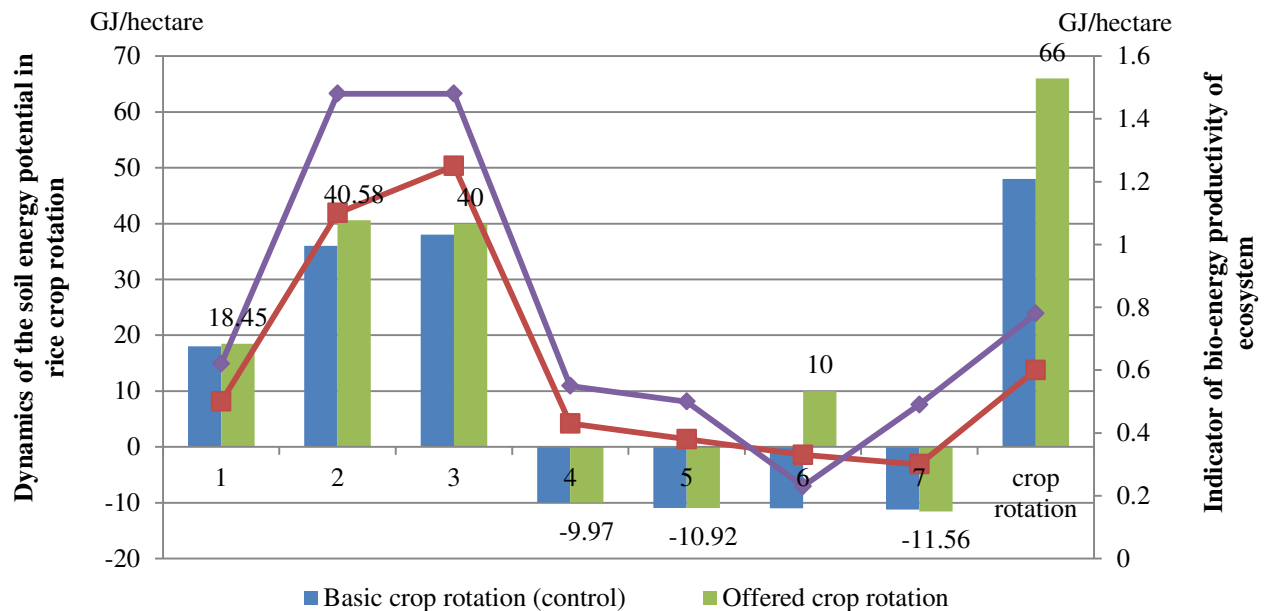


Figure-1. Improving energy potential of deteriorated rice agro-landscapes. Basic crop rotation (control): 1 - alfalfa of 1 year of life + spring barley; 2 - alfalfa of 2 year of life; 3 - alfalfa of 3 year of life; 4 - rice; 5 - rice; 6 - rice; 7 - rice. Offered crop rotation: 1 - alfalfa of 1 year of life + spring barley; 2 - alfalfa in case of flooding of 2 year of life; 3 - alfalfa in case of flooding of 3 year of life; 4 - rice; 5 - mustard, rape; 6 - rice; 7 - rice.

The yield of production increases with minimal costs in case of inclusion of upland crops to the rice crop rotation, and that increases the bio-energy coefficient by 0.46...0.93.

There have been developed, improved and optimized the technologies of associated crops cultivation on residual moisture reserves after the rice cultivation (up to 320 mm).

It is recommended to include mineral fertilizers in amount of $N_{70...100}P_{40...60}$ kg/hectare of active substance at the same time with sowing (norm of 2.5 million pieces/hectare) for formation of sarepta mustard seeds productivity at the level of 1.5...2.02 t/hectare. It is necessary to bring nitrogen fertilizers in $N_{90...120}$ doses of active substance at the same time with sowing for obtaining the planned green weight fertility of 25...35 t/hectare and spring rape seeds of 2.0...2.5 t/hectare. The sunflower agroecosystem is formed with plant population density of 35...40 thousands per 1 hectare, the distance between plants in lines is 20...25 cm, width of line spacing is 45 cm, the dose of mineral fertilizers is $N_{110}P_{45}$. The sowing alfalfa takes 25...30% of the crop rotation area in the Kalmykia rice systems, and is the best predecessor before rice. The biological peculiar properties of this culture make it an irreplaceable in rice crop rotation in economic, agrotechnical and land melioration relations, especially in saline lands. The greatest harvest of rice is obtained from the layer of alfalfa of 7...8 t/hectare, and up to 6.0 t/hectare after its layer crop rotation. It is possible to get 4...5 alfalfa mowings per season with total hay fertility of 8...12 t/hectare in case of agro-technical method's enforcement. It is recommend to sow spring barley of 110...130 kg/hectare and alfalfa seeds of 18...20

kg/hectare for good alfalfa herbage obtaining. Alfalfa seeds processed with rizotorphine at a dose of 200 g per a hectare seeding norm before sowing. Sowing is carried out by a grain-grass seeder SZT-3.6 with the simultaneous phosphorus inclusion in the dose of P_{15} . The recommended dose of phosphorus application is 90...120 kg/hectare of active substance for 2 years reserve of the basic soil cultivation. It is necessary to use additional fertilizing and aeration of the soil by cultivators in the unit with serrated harrows after mowing. The dose for nitrogen fertilizers inclusion is $N_{25...30}$ after each mowing. The measures for 2- and 3- year old alfalfa agroecosystems keeping include early-spring harrowing and autumn slitting of sowings to a depth of 40...45 cm.

The ecological effect through growing crops-ameliorants in rice crop rotations of meliorated field consists the following:

- the rice fields soils are dried better, and it is a result of intensive consumption of and transpiration of water by plants;
- the soil aeration increases and the advance of its physical maturity accelerates in spring, thus the total porosity increases in comparison with the crop rotation unit such as rice-rice by 5...7%;
- the density of summation in crop rotation unit such as rice-crops-ameliorants decreases by 7.52...10.3%, and amount of the most valuable soil aggregates (0.25...10 mm) increases by 9.95...16.04%, and coefficient of structure increases from 0.9 to 1.7...1.9;
- it is provided the reducing of geo-ecological risk of flooding the area by 35%;



- the plowing of rape and mustard crop residues (more than 4.0 t/hectare) to a surface layer of rice fields soil allows to increase the humus content by 15...18%, and that contributes to increasing of biological activity of soil and to increasing of availability of essential nutrients to rice plants. There is an obtained favorable direction of the main processes in soil: oxidative processes dominate before planting rice and recovery processes dominate during the growing vegetation period (after processing of green weight), and this increases the mobility of phosphorus and potassium, which as well as nitrogen are the main elements of rapeseed plants. The total amount of fresh organic matter weight with root and cover residues of the alfalfa receives about 14.6...14.8 t/hectare for three years of research, so the content of humus in the brown semi-desert soil of rice rotation increases in the soil horizon (0...30 cm) from 1.19 to 1.48...1.49%, and in the layer 0...20 cm from 1.24 to 1.52...1.54%;
- more favorable agrohydrological conditions and salt regime of soils are created in case of crops-ameliorants locating in the field with residual moisture reserves (the groundwater level decreases by 0.4...0.6 m, and also their mineralization by 5...12%, and recurrence of salinization do not occur);
- the phytosanitary situation improves in the rice fields in case of spring rape and sarepta mustard plant residues plowing, because physiologically active compounds having a high allelopathy-ability and providing a depressing effect on weeds pass into the soil solution;
- the grain harvest of rice increases by 0.39...1.13 t/hectare in case of cultivation after predecessors – crops-ameliorants.

CONCLUSIONS

Sufficient provision of cultivated crops, including basic crop - rice is necessary to ensure of ecologically safe and highly efficient operation of Kalmykia rice meliorative systems. As far as rice is a meliorative crop, then its cultivation contributes to reduction soil salinity degree and increasing its fertility; the reserves of residual moisture are more than 300 mm in the next year after the rice cultivation that gives an opportunity to get the additional agricultural production (grain, hay, oilseeds). This allows using the meliorated lands and irrigative water more effective, accelerates amelioration of periodically flooded soils of rice fields, increases the crop yield.

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