Ecological paradigm for sustainable functioning of reclamation systems in arid territories

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Abstract. A new ecological paradigm is formed based on environmental issues perceived through the prism of specific social and economic development of society. Sustainable development rests on a positive modification in the existing system of relationships between society and nature in compliance with the principles of ecological balance. The paper deals with the ecological paradigm under safe functioning of ameliorative systems of the Republic of Kalmykia, based on the principles of ecological agroameliorative balance. Based on the criteria for negative impacts, it is found that over 3.0 thousand hectares were withdrawn from the reclamation fund in the area outside Sarpinskaya irrigation and water distribution system, 15% of the territories is susceptible to flooding due to a rise in the groundwater level to 1.3-2.5 m. The efficiency of agroameliorative landscapes was evaluated in three blocks: energy, bioenergy and ecological and economic, which provides a rationale for agricultural methods, reclamation crop rotations, the structure of arable land and sown areas, pursuant to safe and sustainably sourced land and water. Schemes have been developed to design agrolandscapes in the arid-semi-arid zone of the Republic of Kalmykia for highly saline soils with a water-soluble saline content of more than 0.8%, with the following alternation of crops: tall wheatgrass – tall wheatgrass – tall wheatgrass – alfalfa – alfalfa – alfalfa, thus enabling to develop degraded saline lands. In saline areas with close mineralized groundwater occurrence (5-10 g/l), agroameliorative landscapes should be designed in such a way as to provide for the cultivation of ameliorant crops (tall wheatgrass, Jerusalem artichoke), with the bioenergy efficiency ratio to reach 6.10/ha. The findings show that environmentally safe reclamation systems operating in arid territories are possible based on a new methodology for constructing agrolandscapes, recognizing the laws of adaptive production strategy, the natural environment-forming and environment-optimizing functions of plants and predicting development trends for agroecosystems.

1. Introduction
Ecologically safe performance of ameliorative agricultural landscapes is ensured by the balanced impact of natural and man-made factors on the “climate – soil – water – animal world – plant” system. A conceptual Earth’s biogeochemical model developed by scientists from ARRHELR of A.N. Kostyakov is based on the concept of open systems that have stability, self-regulation and are in translational dynamic equilibrium [1,2]. A new worldview paradigm is formed based on the principles of ecological balance of agroameliorative landscapes [1-6]:
- rational and efficient use of natural reclaimed resources;
adaptive reclamation measures based on soil-climatic, hydrological conditions of a particular territory;
− water-saving and soil-protecting technologies for producing agricultural crops;
− technologies for advancing the natural resource potential of degraded irrigated lands by means of complex land reclamation;
− commitment of agricultural producers in preserving the productive potential of reclaimed lands.

Creating agroameliorative landscapes entails consequences that affect cycles of substances in ecosystems shaped over the years thus making them change globally. Therefore, today natural laws and rules used in land reclamation must be correlated with general environmental laws. The laws adopted in land reclamation (the equivalence and irreplaceability of plant life factors, minimum, optimum, maximum, cumulative effect of factors, return, diminishing fertility) determine the interaction of plant life factors in the process of producing a crop. These laws were used as a general theoretical basis for the formation of agroecosystems [4,7,8]. However, today, when farming systems are considered as a toolkit for the design of agricultural landscapes updated in accordance with the requirements of nature conservation, the set of environmental laws and rules for their construction is growing significantly.

The paper aims to study an aggregate effect of factors to design agroameliorative landscapes and to develop environmentally friendly foundations to ensure the performance of reclamation systems.

2. Objects and Research Methods

On the territory of the Republic of Kalmykia, there are five large reclamation systems for irrigation/water distribution purposes: Chernozemelskaya, Kalmytsko-Astrakhanska, Pravo-Yegorlykskaya, Sarpinskaya and Caspian. The total area of reclaimed land is 80.9 thousand hectares, of which customarily irrigated – 44.7 thousand hectares, subject to inundative irrigation – 36.2 thousand hectares. The indicators of the reclamation state of the areas that are customarily irrigated (in terms of GWL and salinity) are as follows: good – 1.8 thousand hectares (3%), satisfactory – 16.7 thousand hectares (31%), unsatisfactory – 35 thousand hectares (66%) [6]. The total area of re-saline irrigated lands with varying degrees of salinity is about 45 thousand hectares or 85% of the irrigated area (Table 1). Re-salinization of a strong and very strong degree is observed at almost all irrigation/water distribution facilities, except for the Pravo-Yegorlyk facility. The current ecological situation evaluated in the Sarpinskaya rice irrigation/water distribution system (IWDS) shows that, of the total area of irrigated land (8,031 hectares), 43% (3,459 hectares) is in a satisfactory reclamation state, and 57% (4,572 hectares) is in an unsatisfactory state due to re-salinization and alkalinization.

| IWDS                  | low  | medium | high     |
|-----------------------|------|--------|----------|
|                       | S, ha| % of total | S, ha | % of total | S, ha | % of total |
| Pravo-Yegorlyskaya    | 2,747| 56.5   | 296     | 6.1     | -     | -         |
| Chernozemelskaya      | 8,426| 36.3   | 6,530   | 28.1    | 3,916 | 16.7      |
| Sarpinskaya           | 7,819| 51.6   | 5,257   | 34.7    | 1,523 | 10.0      |
| Kalmytsko-Astrakhanskaya | 2,798| 33.0   | 3,955   | 46.8    | 728   | 8.6       |
| Caspian               | -    | -      | -       | -       | 1,249 | 100       |
| Total                 | 21,790| 41.0   | 16,038  | 30.2    | 7,416 | 14.0      |
The efficiency of agroameliorative landscapes was evaluated in three blocks: energy, bioenergy and ecological and economic. The man-made costs were determined using a typical technological map, standard production rates, fuel and lubricants costs based on the energy equivalents of the use of agricultural machinery, organic fertilizers, and labor resources. Energy consumption was calculated against direct and indirect investments of energy resources at all stages of a cycle, starting from the production of fertilizers, etc. and ending with harvesting.

**Block I** – energy, represented by energy intensity of production (E) and energy efficiency of agricultural crops (EE):

\[ E = \frac{E_{\text{ane}}}{U_1} \quad (1), \text{where} \]

\[ E_{\text{ane}} \text{ is anthropogenic non-renewable energy, GJ/ha} \]

\[ U_1 \text{ is yield of core produce, kg/ha} \]

\[ \text{EE} = \frac{E_{\text{ph}}}{E_m} \quad (2), \text{where} \]

\[ E_{\text{ph}} \text{ is the energy output of aboveground phytomass, GJ/ha}, \]

\[ E_m \text{ are the costs of total man-made energy for the cultivation of crops, GJ/ha}. \]

**Block II** – bioenergy, characterizes bioenergy productivity of the agroecosystem, the intensity of the energy input from organic matter into the soil during the growing season, the reproduction of soil fertility during the growing season, the use of PAR energy by the agroecosystem.

**Block III** – ecological and economic, determines the productivity of the agroecosystem per unit of labor costs (P):

\[ P = \frac{E_{\text{ph}} + \Delta F}{C_l T_{\text{ph}}} \quad (3), \text{where} \]

\[ C_l \text{ are labor costs for the cultivation of crops, man-hour/ha}. \]

Field studies aimed at the design of agroameliorative landscapes for the restoration of re-saline irrigated lands and evaluation of their effectiveness were carried out on brown semi-desert sodic soils located nearby Chernozemelskaya IWDS of the Republic of Kalmykia. Research options included the following designs:

* zonal irrigated grain-feed crop rotation (control): 1. lucerne 1 f.u. + spring barley; 2. alfalfa 2 f.u. for hay; 3. alfalfa 3 f.u. for hay; 5. winter wheat; 6. Sudanese grass for hay;

* ameliorative crop rotation (I): 1. wheatgrass 1 f.u.; 2. wheatgrass 2 f.u. for hay; 3. wheatgrass 3 f.u. for hay; 4. alfalfa 1 f.u. + spring barley; 5. alfalfa 2 f.u. for hay; 6. alfalfa 3 f.u. for hay;

* reclamation crop rotation (II): 1. wheatgrass 1 f.u.; 2. wheatgrass 2 f.u. for hay; 3. wheatgrass 3 f.u. for hay; 4. Jerusalem artichoke; 5. Jerusalem artichoke; 6. Jerusalem artichoke.

3. **Results and Discussion**

A reclamation regime is formed on the basis of natural conditions and their forecast changes resulting from man-made impacts. One of the main environmental indicators of the reclamation regime in various natural and climatic zones is the level of groundwater and the associated intensity and direction of moisture, salt, heat transfer [1-3]. Academician I.V. Kiryushin [4] notes that concerns about the future of mankind are determined by the following challenges to the civilization of the new century: environmental (desertification, man-made pollution of the biosphere, greenhouse effect); energy (doubling the demand for primary energy, tripling the electricity consumption); demographic (doubling of the population by the middle of the century, different growth rates of states and regions); geopolitical and social (international and ethnic conflicts, redistribution of spheres of influence, etc.).

Among the well-known regulations towards water and saline regimes in irrigated areas, the methods contributing to the minimum capacity of active saline exchange in irrigated areas are of paramount importance. In the arid zone, from an ecological point of view, the main tasks are: preserving the quality of surface and irrigation waters, excluding depletion of river runoff, preventing re-salinization, excluding areas with high geological reserves of salts from reclamation, reducing salinity and volumes of drainage runoff [1,2,6].
In this regard, the environmental assessment of the cultivation of agricultural plants should be aimed, first of all, at identifying the advantages and, accordingly, the feasibility of planting these crops in irrigated areas in a certain soil-climatic zone.

In the natural and economic and ecological conditions of the arid-semi-arid zone of the Republic of Kalmykia, the highest anti-erosion, soil conservation and resource-energy saving function can be achieved as long as reclaimed agrocenoses are designed. Thus, in the zonal grain-fodder rotation on brown semi-arid soils in combination with salt licks, with the alternation of crops: alfalfa – alfalfa – winter wheat – spring wheat – Sudanese grass up to 105.37 GJ/ha of energy accumulates, at energy costs 19.74 GJ/ha. The bioenergy efficiency ratio of this crop rotation is 5.33 (Table 2).

Table 2. Ecological and resource efficiency of agroameliorative landscapes on degraded irrigated re-saline soils

| Variants of schemes for constructing agroameliorative landscapes in reclaimed arid areas | Indicators of the performance of the agroecosystem, GJ/ha |
|--------------------------------------------------------------------------------------------|-----------------------------------------------------------|
|                                                                                           | energy intensity of production | energy efficiency of cultivation | bioenergy productivity of agroecosystem | soil energy potential |
| Grain-fodder rotation (control): 1. lucerne 1 f.u. + spring barley; 2-3. alfalfa for hay; 4. winter wheat; 5. spring wheat; 6. Sudanese grass for hay | 0.44 | 5.33 | 0.54 | 28.48 |
| Reclamation crop rotation (I): 1-3. wheatgrass for hay; 4. alfalfa 1 f.u. + spring barley; 5-6. alfalfa for hay | 0.42 | 3.87 | 0.53 | 37.52 |
| Reclamation crop rotation (II): 1-3. wheatgrass for hay; 4-6. Jerusalem artichoke | 0.43 | 6.10 | 0.83 | 61.46 |

A reclamation crop rotation was developed and introduced for highly saline soils with a water-soluble salt content of more than 0.8%, with the following alternation of crops: tall wheatgrass – wheatgrass – wheatgrass – alfalfa – alfalfa – alfalfa. The bioenergy efficiency ratio is 3.87. Despite being less productive than traditional methods, adaptive landscape technology is ecologically more perfect. It enables to advantage degraded re-saline lands.

In saline areas with a close mineralized groundwater occurrence (5-10 g/l), it is recommended to grow Jerusalem artichoke after three years of cultivation of saline wheatgrass. At the same time, energy costs are 25.43 GJ/ha, with an agricultural output to amount to 155.13 GJ/ha. The bioenergy efficiency ratio reaches 6.10 from 1 ha.

Once evaluated, the efficiency of the technology for managing reclamation regimes based on a new methodology for designing agricultural landscapes in the arid-semi-arid zone of the Republic of Kalmykia provides a rationale for agricultural methods, reclamation crop rotations, the structure of arable land and sown areas pursuant to safe and sustainably sourced land and water.

Provided that degraded re-saline soils are restored with diversification of ameliorant crops into irrigated crop rotations, the energy potential of soils is growing. Thus, for an alternation in the reclamation crop rotation, the accumulation of soil energy is 61.4 GJ/ha, which is 2.2 times more than in the zonal grain-fodder rotation. Besides, the bioenergy productivity of the agroecosystem is 0.83 GJ/ha.

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production strategy, the natural environment-forming and environment-optimizing functions of plants and predicting development trends for agroecosystems.

4. Conclusion
The efficiency of agroameliorative landscapes for the arid conditions of the Republic of Kalmykia was evaluated, which makes it possible to quantitatively assess the level of use of natural and man-made resources, their interrelation and interdependence, to determine ecologically expedient methods of managing the processes of creating energy in the form of plant phytomass and soil organic matter in agroecosystems, to predict the development trends for agroecosystems.

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