THE NECESSITY FOR DEVELOPMENT OF LAND RECLAMATION

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Contents

Summary

In this article, reclamation systems are considered as control systems for environmental conditions with the purpose of building optimal conditions for height and development of biotic assemblages, in particular for agricultural plants. Principles and requirements are formulated, on the basis of natural responses to systems of complex regulation of factors affecting the lives of autotrophs. The stages of decision-making in the development of reclamation systems are considered. General principles of deriving dependencies between productivity and environmental conditions are given. The theory of substantiation of reclamation is developed, and mathematical models are described on the basis of which the classification of reclamation in different ecological zones is developed, permitting determination of the necessity of regulation of various natural conditions. The necessity for single-factor and multi-factor reclamation is described for particular natural zones.

1. Development cycles of methods of complex reclamation regulating.

Reclamation measures can be considered as systems for regulating environmental conditions for the purpose of creating optimal conditions for growth and development of biotic assemblage, particularly for agricultural plants.

The motivation for development of modern systems of agricultural reclamation comes from the conflict between the practically unlimited needs of developing humankind and our restricted ability to use natural and human-made resources.
As a result of evolution, the ancestors of modern plants developed in such a way that conditions in their places of origin became ecologically optimal for each species. Humans increased the productivity of natural species through cultivation and artificial selection, but their tolerance of changing environmental conditions, which was a peculiar feature of every species, was reduced. In the course of human migration from one region to another, plants were transferred to terrain with essentially different, and less optimal, natural conditions for each species. At the same time, in the process of economic activity, humans significantly changed their local environment—a process which had a negative impact on native plants. In this situation, the balance between the structural-functional adaptations of plants and their environment was disturbed. The time necessary for evolutionary acclimatization of plants, far exceeds the time of their exposure to the new and the changed conditions. Humankind was forced to seek a radical improvement of environmental conditions, both to maintain the growth and development of agricultural plants, and to restore natural conditions in the disturbed areas.

Thus, the need for creating optimal conditions for agricultural plants and restoration of natural ecosystems stems from incompatibility between the requirements of plants (autotrophic part of the ecosystem) and the environmental conditions. In future, we can expect human activity, of all sorts, to be increasingly incompatible with natural biological systems.

Humans selected and developed extremely productive plants, and these have replaced natural communities over very large areas. Their productivity is 50–100 times that of their remote ancestors. But a consequence of this high productivity is the reduction of natural acclimatization (3-5 times). Certain factors, which may be small in absolute magnitude (e.g. trace elements, micro-doses of toxic gases, etc.), become limiting at the optimal level of the others, and begin to exert a significant influence on productivity. From a minor level of disturbance to the ecosystem, the maintenance of a stable state becomes impossible without precise adjustment of a complex of environmental factors.

The principles and requirements for a system of complex regulation for production of autotrophs can be formulated as follows:

- Maximum utilization of insolation and photosynthesis of active radiation (PAR) by the crops—this is a key and under-lying criterion;
- All factors are regulated actively and purposefully;
- At every moment of growth and development of plants, the value of the limiting factor is adjusted to a level within the optimal range;
- Optimal conditions are created at the critical moments for growth and development of plants;
- The error of adjustment should be significantly less than the width of the optimal range of acclimatization of a plant;
- Priority should be given to providing optimal conditions for the growth and development of the plant species which is in the most depressed state;

- For normal operation of a system of complex regulation, the stochastic heterogeneity of soil properties and nutrient stocks, and non-uniformity of natural fertility in the catchment, should be taken into consideration.
- For creation of a naturally-restoring system, it is necessary to achieve not only high productivity of plants, but also increasing fertility of the land;
- Ecological safety must be ensured by building closed cycles with re-generation of energy and matter flows in adjoining ecosystems up to the natural level.

To solve all the relevant problems through the regulating process, it is necessary to have a quantitative expression of the requirements of plants (and biota in general), and the environmental conditions. Later on, knowing to what extent environmental conditions do not correspond to the requirements of biota, it is possible to determine the minimum influence necessary to achieve the desired result.

After evaluation of the necessary regulating actions, selection of the executive devices corresponding to each adjusted factor can be made. The next stage is synthesis and integration of the devices for regulating the aqueous, thermal and nutrient conditions.

The development cycles of methods of complex reclamation and regulation can be displayed by the scheme proposed by Professor V.V. Shabanov, in stages, as follows:

The requirements of plants, and subsequently, of any living organism, to environmental conditions according to a number of macro-factors (aqueous $\mathbf{S_w}$, and thermal $\mathbf{S_t}$ conditions, mineral nutriment and gas nutriment $\mathbf{S_f}$, solar energy $\mathbf{S_r}$) and micro-factors (trace elements and micro-concentration of gases) are explored. In this case, the requirements of living organisms are seen as a quantitative interrelation showing their change of productivity in relation to environmental conditions and anthropogenic action. For the purposes of regulating, it is necessary that the requirements of plants and microorganisms are expressed as quantitative dependence, i.e. the corresponding mathematical models must be developed. Thus, understanding of the general mechanism of interaction of a plant with its medium, and construction of theoretical models, has to be considered the first objective.

Study of the mechanism of formation of environmental conditions and the quantitative expression of these processes forms the second group of mathematical models. First it is necessary to solve the problem of mathematical description of environmental conditions. The form of this description should reflect in the best way the essence and nature of the circumscribed magnitude. The descriptions can be split into determined and probabilistic ones. It is known that meteorological processes, which are ultimately controlled by solar activity, are random in time. It is these processes which determine precipitation, temperature, wind and other environmental conditions. Therefore, probabilistic, or stochastic, description should be adequate for describing environmental conditions. However, it is possible to express the mechanism of generating aqueous **W (x, y,ι)**, thermal **T (x, y, ι)** and nutrient conditions **F (x, y, ι)** at every point in space by determined differential equations that are widely used today. Applying to them the law of distribution of probabilities of conductivity coefficients, it is possible to obtain the stochastic mechanism of generation of environmental conditions and thereby to connect the stochastic and determined methods of description of environmental conditions.

The research in the first two stages can be generalized in this *third stage* in the form of an indicator of the need for reclamation/amelioration measures. This indicator is based on information on the requirements of living organisms and the prevailing environmental conditions, i.e. the probability is reflected of optimal ($\mathbf{P_w, P_t, P_f}$) or non-optimal ($\mathbf{\overline{P}_w, \overline{P}_t, \overline{P}_f}$) requirements for a plant in a specified geographical region. In a certain sense this parameter can be termed bioclimatic. Thus, the features of soil-generating processes, which are the most important for substantiation of nature protection measures, are manifested in aqueous, thermal and nutrient conditions of bedrock and soil. Depending on the initial information used for describing the environment (and on the stage of development), the indicator of need for action reflects either the general geographical conditions if it is based on climatic data, or the microclimatic conditions of marshes, irrigated areas or other kinds of land. The climatic indicator can be used for determining the directions of nature management and environmental engineering over vast areas, and also for planning the lay-out of engineering works and energy expenditures for creation of the optimal conditions. The microclimatic indicator of necessity for regulating action is applied to a discrete area of land. It is possible to obtain these parameters, using mathematical models. Thus, evaluation of probability of optimal or non-optimal requirements is the subject of the *third stage* of the decision-making process. It is necessary to note, that determining need in environmental factor management can be either single-factor, or multi-factor. The probability of non-optimal aqueous $\mathbf{\overline{P}_w}$ *or* thermal $\mathbf{\overline{P}_t}$ conditions is calculated in the first case, and in the second case non-optimal aqueous, thermal, nutrient *and* radiation requirements ($\mathbf{\overline{P}_{w, t, c, f, r}}$) are calculated

The maximal range of regulation of environmental conditions is determined for every factor ($\mathbf{D_{max}}$,). All the probable deviations of environmental conditions from the optimal, are included within this. The maximal range of regulating determines the limits of the regulating system and is used in this *fourth stage* of its development.

Operative control of the regulating process plays an important role—the calculation of this constitutes the subject of this *fifth stage*. This involves a measure of prediction, i.e. the difference between the requirements of plants, or other biota, and the predicted magnitude of external factors should be continuously calculated. Therefore the main problem for research at this stage is the development of methods of prognosis of controlled magnitudes and calculation of control actions for each factor ($\mathbf{\Delta w, \Delta t, \Delta c, \Delta f, \Delta r}$), with allowance for their interaction.

This *sixth stage* involves the solution of a number of problems related to engineering realization of the desired aqueous, thermal and nutrient conditions, including the problems of automation of processes of complex regulating. The calculation of regulating systems can be realized only where there is knowledge of the mechanism of nutrition, water and heat dispersement from the executive element to the plants. Since the medium, in which this occurs is of a complex stochastic geometry, the mechanisms of water, heat and nutrition dynamics are not yet developed in many respects. Therefore, the study of how water, heat and nutrients move from an executive element to the plants, together with the change of soil properties under the influence of water and solutions, is one of the research problems of the sixth stage. Based on this, it is necessary to decide, what the time-lag can be for various types of regulating devices and

methods, and the optimal distribution of regulators over the terrain, with allowance for its spatial heterogeneity.
The regulating of a single factor can be realized in many ways, but it is a lot more difficult to keep a number of factors at an optimal level. Therefore, in the *seventh stage* the problem of optimization of regulators, both single-factor, and multifactor has to be solved. First of all, the criteria of optimization, depending on the problems faced in the regulating, should be defined. Then it is necessary to choose mathematical methods which are most convenient for solution of the specified problems. However, it is necessary to take into account, that the optimal single-factor systems might be non-optimal when working in a complex of factors, so it is necessary to search for multi-parameter optimality criteria. Apparently, some optimality criteria have an economic structure. This circumstance makes it necessary to study some technological parameters and economic links. Thus, this stage provides the calculations necessary for the reclamation system to restore or maintain the desired equilibrium in growing conditions. Nevertheless, it would be wasteful not to use information obtained from a single object, if it can be applied for similar development of other objects. In this case, extrapolating the results is impossible if there is no certainty of the level of basic properties of the considered objects. Certainty can be assured only on the basis of quantitative assessment of similarity of the objects. Such assessment can be expressed in the form of quantitative multi-parameter classification of natural objects. These problems are explored in this *eighth stage*. Here a number of problems appear, the solutions for which are only just beginning to arrive. is the include: the problem of integration of multi-parameter data and their representation in a form convenient for making calculations, the problem of definition of class patterns, the problem of choice of criteria of affiliation with the class, and a number of others. Furthermore, at this stage, the computing programming problems are very important, as some multi-factor algorithms can only be run with the help of a computer.

The *ninth* and final *stage* of the research includes the development of methods of computer-aided design, which can be accomplished, for example, by searching for the optimal variant of regulating for the objects of each class.

Let us consider the *third stage* of the research in more detail. According to the aforesaid, this stage is a generalization of the requirements of plants and environmental conditions in the study area. If the requirements of the plants and the soil conditions coincide as regards the major factors (aqueous, thermal, radiation and mineral nutrition), then the natural/anthropogenic system is in a stable state and no measures are necessary for its maintenance. However, in view the stochastic character of environmental conditions, it is more expedient to determine the requirements of plants as a probability of occurrence of non-optimal environmental conditions both against every factor, and against a set of all factors.

This probability can be calculated repeatedly during the period of growth and development of plants, for example, once every ten or five days. If the probability of optimal conditions is great (P_{opt} > 0.7-0.8), a reclamation system aimed at correcting environmental conditions is not required. If the probability of non-optimal conditions is great, it is necessary to provide control actions, to restore optimality. Thus, the considered operation in the indicated form combines data on the requirements of plants and environmental conditions into one parameter.

Depending on the materials initially used to describe the environment, this parameter will reflect either the general geographical mechanism, if it is calculated on the basis of macro- and meso-climatic data, or a microclimatic mechanism related to drained marshes, irrigated terrain or other kinds of reclaimed land.

The climatic parameter of reclamation requirements is applied for definition of the general direction of reclamation work. It can be used for planning of allocation of reclamation zones and assessment of energy expenditure for generation of optimal conditions. The microclimatic parameter, on the other hand, is applied for planning the reclamation actions, i.e. for detailed calculation of the regulating system.

We shall consider the procedure of evaluation of the statistical parameters of reclamation requirements. From the mathematical point of view, this problem is set as follows: to determine the probability of occurrence of non-optimal environmental conditions for a plant, if the environmental requirements of the plant and the environmental conditions are known and expressed in the form of distributive laws of aleatory (unpredictable) variables or random functions of environmental factors.

The distributive laws can be obtained from solution of stochastic differential equations, or they are defined on the basis of perennial observations. The solution of the set problem is obtained in the form of probabilities of ***necessity (requirement) of reclamation*** $\bar{P}$.

The probability is repeatedly calculated throughout the period of vegetation, for example once every ten days. This allows the evaluation of need for reclamation actions every ten days. If the probability of non-optimal requirements is great: $\bar{\mathbf{P}} \geq \mathbf{0.6}$, it is necessary to provide for reclamation actions, the probability of which will be equal to the probability of the non-optimal requirements.

Thus, the substantiation of reclamation requirements of the indicated kind combines the data on the requirements of plants and environmental conditions into one parameter.

What requirements should the parameter of reclamation need correspond to?

The parameter should completely reflect the requirements of plants in relation to environmental factors.

It should completely reflect the environmental conditions, in particular the stochastic nature of soil factors.

It should be constructed on the basis of environmental factors which can be controlled. For example, the aqueous factor can be expressed as moisture content in a particular layer of soil, so that it is simple to calculate the system supporting this moisture content within the optimal range.

The calculated period, for which the parameter of reclamation need is calculated, should be short enough to assess a change of the parameter during the whole period of vegetation. It allows the marking of critical periods in which particular kinds of reclamation are given higher priority.

The parameters of reclamation of each factors should be generated successively so that a single-factor parameter is a special case of a two-factor parameter, and the last one is a special case of a three-factor parameter, etc.

The parameter of reclamation need should have a clear physical sense. For example, it should allow determination of the frequency of this or that kind of reclamation required for a specified object.

1.1. Kinds of land reclamation

Regulation of the aqueous, thermal, nutrient and other conditions on reclaimed land can be accomplished by many means. Surplus moisture is controlled by drainage of land, and lack of water by irrigation. Surplus of chlorides is controlled by desalination (flushing the soil with fresh water and removal of saline water through drainage). Shortage in the soil of such substances as nitrogen, phosphorus, potassium and others is controlled by supplying fertilizer, either in solid or liquid form. Soil temperature can be adjusted by mulching the soil or through irrigation with sprayed water. Classification of kinds of reclamation was developed by Professor B.S. Maslov.

Reclamation systems accomplishing the regulating of conditions against many environmental factors can be called systems of complex reclamation regulation. Such systems are most effective within the frameworks of adaptive landscape agriculture.

Complex reclamation regulation within the framework of a system of adaptive landscape agriculture consists of the following:

1. Creation of aqueous, thermal and nutrient conditions of soils, to promote:
   the reduction soil compaction (regulating the terms of spring “maturing” of the soil, regulating the consolidation of soil through optimal control of groundwater, etc.);
   achieving greater efficacy of recycling of organic sources of nitrogen and use of organic fertilizers;
   optimization of ion exchange and microbiologic activity;
   maintenance of populations of the natural enemies of pests;
   depressing the sources of plant diseases;
   reducing soil erosion and leaching of chemical elements into groundwater.
2. Locating agricultural crops with due regard for the landscape (exposure on hillsides, slopes, and geomorphology).
3. Optimization of aqueous, nutrient and thermal conditions of soils for each crop of the crop rotation, promoting the maximum use of the adaptive abilities of agricultural crops.

In alternative agriculture, soil nitrogen is managed by application of manure and composted plant material or ‘green manure’. These techniques are gradually replacing inorganic nitrogenous fertilizers.

In the system of complex reclamation regulating these measures produce the following effects:

reduction of denitrification by leaching and evaporation;

reduction of nitrogen waste through its consumption by weeds; this works if the program is applied correctly, (i.e. the nutrient elements are applied at the right time, close to the time of maximal consumption by the crop plants), and is most effective with the help of sprinkling and sprinkling-irrigation systems;

slowing down the process of mineralization of organic elements in soil through active control of aqueous and thermal conditions and satisfaction of the long-term nutrient requirements of plants;

regeneration of organic elements of soil, its structure, ion exchange capacity and microbiological activity.

The program of raising soil fertility cannot be separated from the scheme of crop rotation. Crop rotations are necessary because they allow crop plants to absorb the nutrients left behind by the previous crop, and, besides, integumentary crops are able to bind soil nitrogen, which prevents leaching and allows it to be released slowly over a longer period, as the plants decompose.

Appropriate choice of crops in a rotation extends the effectiveness of systems of complex reclamation regulation, as these systems create more varied environmental conditions, optimal for different plants.

In the next section we consider in more detail the set of mathematical models for substantiation of necessity of reclamation.

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Biographical Sketch

Shabanov, Vitaliy Vladimirovich, Doctor of Technical Sciences, Professor of the Moscow State University of Environmental Engineering, Academician of the Russian Academy of Agricultural Sciences V.V. Shabanov was born on June 27, 1937, in Moscow, into the family of hydrologist. In 1964, he graduated from the Engineering Department of the All-Union Institute of Extension Education in Agriculture; in 1991, he took the retraining course in Ecology at Moscow State University and got the diploma of Expert in Ecology

His scientific career started in the Yakutian Expedition of the Research Center of Moscow Institute of Hydraulic Engineering and Water Management, where he worked as a laboratory assistant and then junior researcher from 1956 to 1966. In 1966, he headed the works on the creation and maintenance of the automated system of water regulation on reclaimed lands in Byelorussia. From 1972 to 1987, he was the Head of the Laboratory of the Problems of Regulation of Water, Temperature, and Salt Regimes of Reclaimed Lands; since 1987, he has been a scientific supervisor of this laboratory. From 1981 to 1995, he headed the Chair of Multiple Use and Management of Water Resources. Since 1995, he has been a professor of the Chair of Amelioration and Rehabilitation of Lands of the Moscow State University of Environmental Engineering.

In 1969, V.V. Shabanov defended his Candidate Sci. dissertation on the feasibility of land reclamation measures; his Doctoral dissertation (1992) was devoted to quantitative methods of assessing and regulating the factors controlling crop development under conditions of reclaimed lands.

Scientific interests of Prof. Shabanov are connected with mathematical modeling of economic efficiency and environmental security of land reclamation projects, including the models describing the interaction between plants and environmental factors and the optimization of the use of water resources upon irrigation. His recent works were aimed at assessing changes in potential crop yields under various climatic scenarios and developing the methodology for monetary evaluation of environmental factors for land reclamation projects and optimization of investments.

Professor Shabanov is the author of more than 150 scientific works, including two monographs: "Bioclimatic Factors and Land Reclamation" (Leningrad: Gidrometeoizdat, 1973) and "Water Supply of Spring Wheat and Its Calculation" (Leningrad: Gidrometeoizdat, 1981). He is a co-author of two textbooks on the multiple use of water resources and related issues of environmental protection.