Multi-criteria optimization of the arable land use

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Abstract. The article concludes that it is necessary to optimize the use and reproduction of productive lands, taking into account the intensity of the natural and anthropogenic load on cultivated lands and the possibilities for their improvement. Improving the stability of cultivated lands is proposed to provide on the basis of a compromise between the economic and environmental orientation of agro-economic systems. The procedure of optimizing the use of productive land, taking into account the assessment of the stability of cultivated lands, is demonstrated. The solution of this problem consists in optimization of the arable land structure using multi-criteria optimization methods in the search for a compromise solution by minimizing the weighted amount of pull-backs from the extreme values of the criteria used (the sum of net or gross income, integral estimates of resistance to anthropogenic load, wind and water erosion).

1. Introduction

The orientation of economic entities of the agrarian sector only to market mechanisms for regulating land use processes in the face of risks and uncertainty and weak regulatory influence of the government objectively determines the priority of short-term economic goals and the need to solve tactical and operational tasks of reproduction. In the strategic perspective, the orientation on profit growth due to an increase in the intensity of farming and the increase in the anthropogenic load on cultivated lands may lead to accelerated degradation of productive lands and decrease in their consumer properties.

In this regard, the importance of forecasts will increase, which allows evaluating the prospects for the reproduction of agricultural land at different intensities of the anthropogenic load, taking into account the specifics of the existing cultivated lands and the possibilities for their improvement.

Traditionally, the issues of increasing the sustainability of cultivated lands have been reduced to increasing land areas with a stabilizing effect on cultivated lands (fallow lands, forests and perennial plantations, natural forage lands, land under water, etc.), and reducing land areas destabilizing cultivated lands (arable, irrigated and drained lands, lands under roads, ravines, etc.). Such an approach is fully justified from the point of view of ensuring the environmental sustainability of ecosystems, but it does not provide scientific substantiation for the compromise between the economic and environmental interests of the society and business, business and society, society and individuals. It is obvious that the satisfaction of the growing needs of the society is impossible without the increase in the anthropogenic load on the productive land, especially in areas of intensive farming. But the task for the government as the macroregulator of land relations and the key subject of strategic land management is to balance the economic and environmental interests of the society and to create conditions that ensure rationality of land use while maintaining the sustainability of cultivated lands.

At present, land use optimization by agricultural manufacturers, in most cases, is carried out on the basis of economic efficiency criteria (maximizing the amount of profit, gross or net income depending on the
2. Results and Discussion

When optimizing cultivated lands, the emphasis, as a rule, is placed on increasing the proportion of lands that have a stabilizing and destabilizing effect on the stability of a particular agricultural landscape, and the preservation of biological diversity.

In our opinion, it is necessary to update the approaches to improving the sustainability of cultivated lands on the basis of reaching a compromise between the economic and environmental orientation of agro-economic systems. The implementation of this approach requires special attention to optimize the use of such type of agricultural land as arable land, which is classified as an element that destabilizes an agricultural landscape, but is the main source of creating economic benefits in the system of agricultural production. In this regard, the importance of assessment of the impact of individual crops and their groups on the sustainability of cultivated lands and the reproduction of consumer properties of productive lands increases.

When assessing the environmental value of agricultural crops, it is necessary to consider a multidimensional set of factors of their impact on the processes of using productive lands and functioning of cultivated lands.

Unfortunately, at present, the system of objective indicators reflecting the quantitative and qualitative complex and particular influence of individual crops or their groups on the ecological state of the soil, the stability of cultivated lands and the reproduction of soil fertility and its other consumer properties is not substantiated. In this regard, the criteria derived from expert assessments began to acquire more and more widespread use. Most often, the indicators of soil resistance of various crops to erosion and deflation are used as such criteria.

But the assessment of the conditions for the reproduction of agricultural land suggests that at present the greatest threat to the degradation of productive land is associated with an increase in anthropogenic load and the development of erosion processes. In modern academic literature, the emphasis is usually put on assessing the level of anthropogenic load on the cultivated land as a whole, while in optimizing the land use of the agricultural sector companies, it is extremely important to assess the value of individual crops and their groups by their anthropogenic impact on arable land, and therefore on the whole agricultural landscape as a whole. In our opinion, it is impossible to deny the varying level of anthropogenic load put on arable land by various agricultural crops, due to different levels of intensity of their cultivation technologies.

Obviously, each agricultural landscape is described by its own combination of factors that present the threat of soil degradation. If for some cultivated lands the processes of water or wind erosion pose the greatest danger, for others it is the increase in the intensity of the use of arable land. In this regard, we consider it necessary, when optimizing agricultural land use parameters, to assess not only the potential level of net or gross income from agricultural activities, but also the level of environmental safety of land use according to criteria such as arable land resistance to water and wind erosion and the level of impact intensity on the soil. If necessary, the range of these criteria can be extended, and they can be easily introduced into the optimization model in the form of variables and limitations [7-13].

Optimization of the composition and structure of cultivated lands can be carried out both at the level of land use of individual economic entities of the agricultural sector, and at the level of larger territorial units (regions, districts or their groups, united according to some feature).

The proposed procedure of optimizing the use of productive land, taking into account the assessment of the stability of cultivated lands, involves the implementation of several stages.

At the first stage, an economic and mathematical model is developed, which allows to determine the optimal structure of arable land, based on the level of economic efficiency of agricultural production for
agricultural organizations and peasant farms, and to estimate the average level of intensity of agricultural
crops impact on the soil and wind erosion, taking into account the assignment of the area to a specific
agricultural landscape group.

Optimization of land use of households is not included in this research scope, since organizing land use
management for a large mass of small land users with a heterogeneous target orientation and different
resource potential is extremely difficult within the existing organizational and economic mechanism for
rural development control. But at the same time, we are aware of the problems associated with a sharp
increase in the size of unused agricultural land in household farms, the impossibility to form relatively large
land units for joint cultivation under the conditions of the existing cross-strip, a decrease in soil fertility, the
quality of their phytosanitary condition, etc.

At the second stage, the optimal arable land structure is determined for agricultural organizations and
peasant (farmer) farms with four different criteria of optimality: maximizing net or gross income,
minimizing the integral assessment of the intensity level of crop impact on soil, erosion and deflationary
danger. That is, the extreme values of the target functions and the structure of arable land are determined,
ensuring their achievement with the fixed size of the livestock industry.

At the third stage, the developed economic and mathematical model is complemented by variables and
limitations that allow multi-criteria optimization of arable land structure in the search for a compromise
solution by minimizing the weighted sum of pull-backs from the maximum possible value of each criterion.

The basic economic and mathematical model for optimizing the use of productive land is described as
follows.

To maximize the income function of agricultural production:

$$Z_{\text{max}} = \sum_{j \in J} c_j x_j - X'$$  \hspace{1cm} (1)

where: $c_j$ – the cost of commercial products per 1 hectare of the j-th crop or per structural head of the j-
th species of farm animals and poultry.

With the existence of the following limitations:

Concerning the land resource use:

$$\sum_{j \in J} a_j x_j \leq B_i$$  \hspace{1cm} (2)

where: $a_j$ – the consumption of land resources of the i-th type required for location of 1 hectare of the
j-th crop or the j-th type of the natural forage land;

$B_i$ – availability of the i-th type of resources.

Concerning the population of agricultural animals and poultry:

$$x_j \leq P_{ij}$$  \hspace{1cm} (3)

where: $x_j$ – the population of the j-the species of agricultural animals and poultry;

$P_{ij}$ – availability cattle stalls for the i-th type accommodation of the j-th species of animals.

Concerning meeting the agrotechnical requirements:

$$\sum_{j \in J} x_j = Q_i$$  \hspace{1cm} (4)
where: $Q$ – saturation point of crop rotation with the $j$-th crop or their group.

Concerning provision of the animal husbandry with forage:

$$\sum_{j \in J} k_{ij} x_j + \sum_{j \in J} f_{ij} x_k - \sum_{j \in J} t_{ij} x_j \geq 0$$

where: $k_{ij}$ – yield of the $i$-th type of forage from 1 hectare of the $j$-the crop or the $j$-the type of natural forage land;
$f_{ij}$ – fodder unit content in the $j$-th type of the purchased forage and supplementary feed;
$t_{ij}$ – the $i$-th type of forage required per 1 structural head of the $j$-th species of agricultural animals and poultry.

Concerning the determination of the commercial product prime cost:

$$\sum_{j \in J} c_{ij} x_j = X$$

where: $c_{ij}$ – commercial product cost per 1 hectare of the $j$-th crop or per 1 structural head of the $j$-th species of agricultural animals and poultry.

Concerning the determination of the sum of the production expenses:

$$\sum_{j \in J} s_{ij} x_j = X'$$

where: $s_{ij}$ – production expenses per 1 hectare of the $j$-th crop or per 1 structural head of the $j$-th species of agricultural animals and poultry.

Concerning the determination of the comprehensive assessment of the intensity level of the impact of crops on the soil:

$$\sum_{j \in J} u_{1ij} x_j = U_1$$

where: $u_{1ij}$ – coefficients of the intensity of impact of the $j$-th crop on the soil.

Concerning the determination of the comprehensive assessment of resistance to water erosion:

$$\sum_{j \in J} u_{2ij} x_j = U_2$$

where: $u_{2ij}$ – coefficient of the erosion threat of the $j$-th crop.

Concerning the determination of the comprehensive assessment of resistance to wind erosion:

$$\sum_{j \in J} u_{3ij} x_j = U_3$$

where: $u_{3ij}$ – coefficient of the deflation threat of the $j$-th crop.

Concerning the term of the nonnegativeness of all the variables:

$$X \geq 0, X' \geq 0, X'' \geq 0, U_1 \geq 0, U_2 \geq 0, U_3 \geq 0$$

At the second stage, the optimal parameters of the system are determined, allowing to ground the structure of the crop areas, providing minimal levels of intensity of impact on the soil and erosion and deflationary danger. The economic and mathematical model is implemented with three new criteria of optimality, formalized as follows:

$$Z_{\min} = \left( \sum_{j \in J} u_{1ij} x_j - U_1 \right) / P$$
where $P$ – arable area of the agricultural organization or farms.

In order to solve the problem of smoothing the objective controversies between the economic and environmental orientation of the agricultural enterprises and the need to find compromise solutions that harmonize the economic and environmental interests of agricultural producers, it is suggested to use multi-criteria optimization methods, in particular, a compromise solution by minimizing the weighted amount of pull-backs for each criterion.

Implementation of this method suggests introduction in the economic and mathematical model the auxiliary variables $X_{u1}, X_{u2}, \ldots, X_{un}$, denoting relative pull-backs for the corresponding optimality criterion $Z$. At the same time it is necessary to determine the significance of each criterion, for example, using the method of expert assessments to evaluate the relative weights of these criteria of optimality $p_1, p_2, \ldots, p_n$ ($p_1+p_2+\ldots+p_n=1$).

The calculation of the size of the pull-backs is carried out using the auxiliary limitations of the following type:

$$U_{ZU} X = Z_{max} U_i$$

$$U_{ZU} X = Z_{min} U_i$$

After the introduction of the auxiliary variables and constraints, the economic and mathematical problem is solved to the minimum of the target function:

$$Z_{min} = p_i \sum_{j=1}^{n} X_{uj}$$

The implementation of this economic and mathematical model makes it possible to substantiate the parameters that ensure the achievement of the compromise between the economic and environmental orientation of economic entities of the agricultural sector, taking into account the influence of a combination of factors (the list of factors can be adjusted depending on the objectives of the study), the significance of each of them can be described by weights. The use of this technique provides an opportunity to assess the level of "loss" of income from carrying out landscape protection measures and substantiate the rational level of their compensation from the state, in the case of the development of state programs for the protection of productive land and optimization of cultivated lands.

3. Conclusion

Obviously, in the existing conditions, no economic entity would agree to reduce profits for the sake of improving the quality of the cultivated lands and the level of environmental safety of land use. Within the framework of the strategic land management system, it is necessary to design the mechanisms for compensating the “falling out” incomes of agricultural producers and the state incentive system for landowners and land users to encourage environmental protection measures, removal of the arable land with high level of erosion and deflationary risk and change their permitted use. In addition, it is necessary to develop measures for the conservation of arable land withdrawn from the economic turnover in order to prevent their degradation.

With the current attitude of the state to the problems of optimal use of productive land in the process of agricultural production, economic entities of the agricultural sector will focus only on the criterion of economic efficiency, while continuing to ignore the requirements of scientifically based farming systems and principles of rational organization of land use, which in the long run can lead to degradation of productive and cultivated lands.
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