Methodological Approaches to Environmental Assessment of Productivity Landscapes


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Abstract: On the basis of the fundamental laws of nature characterizing the material and energy balances of the natural system, associated with additional inflow of matter and energy, has developed and proposed a new conceptual model of environmental assessment productivity landscapes, including: model environmental assessment productivity landscapes; integral model of the ecological assessment of the productivity of the landscape, which is a bioenergetic natural resource system, expressed through the productivity of plants and soil; model bioecological assessment the productivity of landscapes.

Key words: Fundamental - Environmental - Landscape

INTRODUCTION

Solution of a number of important issues geography - landscape-geographical zoning of the natural system, associated with the need for reliable quantitative forecast of productivity of landscape. These issues include: landscape-ecological zoning of the natural system; rational distribution of productive forces of the agro industrial complex and ecological-economic evaluation of lands.

Modern achievements in the field of geography, ecology, environmental bioenergy and meteorology allow on the basis of a systematic study of the ecological and functional characteristics of the components of the natural system to develop reliable methods of quantitative and qualitative assessment of productivity of landscapes. Environmental assessment productivity landscapes should understand complex or integral characteristics of the climate, soil and other factors positively influencing the growth and development of plants and soil, representing the energy resources of natural systems. The ecological assessment of the productivity of landscapes should be based on the use of geographic patterns in scale territorial units of different hierarchical rank, which gives the possibility to explain the nature of the formation and functioning of landscape systems of river basins.

Thus, the choice of models and criteria for the assessment of productivity of landscapes should be determined by the nature described geosystems, the class of solvable problems and availability of materials characterizing the state of the components of the system. Using such models is solved a number of important prognosis tasks in the field of nature management, zoning of the natural system in the factors of environmental assessment productivity landscapes and on the basis of rational distribution of productive forces and rational use of natural resources.

MATERIALS AND METHODS

Mathematical Modeling of the Environmental Assessment of the Productivity of Landscapes on the Basis of the Energy Resources of the Natural System:
Living organisms and their groups in the natural system are self-adaptive systems. The enjoyment of their biological functions accompanied by the expenditure of energy obtained from the environment. All processes occurring in organisms or their communities, related to utilization of energy, converting it from one form to another and, with its inevitable scattering. Productivity, or the intensity of the biological process in the landscape, largely determined by the value of the coefficient of use of the free energy ($\eta_i$) system of the trophic level, in which he includes:

- Plant productivity can be determined by the condition of the [1]: $PP = R \cdot \eta / C$;
- Energy spent on soil formation [2]: $Q = R \cdot \alpha \cdot \eta / C$, where $PP$ - the potential productivity of plants; $C$ - calorie yield unit of organic substances; $Q$ - the energy which goes on soil formation, kJ/cm²; $\alpha$ - coefficient taking into account the state of the soil surface; $\eta_i$ - utilization of free energy: $\eta_i = k_f/100$ where $k_f$ - utilization plants photosynthetic active radiation.

Productivity plant communities landscapes ($PP$) depends not only on the energy of the natural system ($R$) and the utilization of free energy ($\eta_i$) and the coefficient of moisture area ($\eta_m$), i.e. [3]:

$$Y_i = PP \cdot \eta_m = R \cdot \eta_i \left( \frac{1}{C} \right)$$

where $Y_i$ - ecological productivity of plant communities with regard to the natural moisture of the landscapes.

In the natural system, the principle of the energy balance of the heat and humidity is observed in natural conditions, where the radiation dryness index ($\bar{R}$) is equal to 1.0. Therefore, as a criterion of the level of radiation drought index ($\bar{R}$), you can take the limit within 0.9-1.0.

Then, potentially possible energy expended in the soil formation process ($Q_i$), can be determined by the formula: $Q_i = R \cdot \exp (-0.9 \cdot \alpha_i)$

Thus, the ecological productivity of landscapes ($K_i$) determined by the ratio of such averaged indicator values as the ratio of the productivity of plants ($K_p$) and soil ($K_s$): $K_i = K_p \cdot K_s$, where $K_p$ is a coefficient characterizing the ecological productivity of plant communities: $K_p = Y/PP$; $K_s$ - coefficient characterizing the ecological productivity of the soil: $K_s = Q_i/Q_i$.

Thus, the developed model environmental assessment productivity landscapes allows you, firstly, to give a quantitative values of qualitative changes of habitats; secondly, modeling transformation of natural systems to climate change; third, landscape-ecological zoning of the natural systems of the river basin.

**Integrated Mathematical Model of Environmental Assessment Productivity Landscapes:** In the last decade, according to study environmental assessment of the productivity of the natural system of environmental factors and their assessment of changes in the landscape or agricultural landscapes in terms of human activities and anthropogenic stresses uses a system of bio-energy analysis, ensuring high reliability calculating the productivity of plants and soil [4].

The principle of bioenergy focus structures and functions of natural systems allows to largely eliminating fundamental difficulties of quantitative and qualitative assessment and forecast of productivity of plants and soils in different climatic areas [5].

We denote the value $x_j^i(k)$ factor $j$ in the $k$ geographical areas $i$ of the period. This may be the amount of biologically active air temperature, evaporation, moisture ratio or hydrothermal indicator and other characterizing the environment, forming peculiarities of the natural system. Through $f_j$ denote the function characterizing the response of plants and soil $j$ -factors $i$-of the period. We assume that it depends on a vector of parameters, i.e. $f_j = f_j(x_j^i(k))$. Existing data allow accepting the hypothesis of a multiplicative influence of factors on productivity of plants and soils [88], meaning the aggregate effect of all the factors in $k$ geographical zone $i$-the period determined by the value:

$$\prod_{j=1}^{n'} f_j(a_j^i, x_j^i(k))$$

where $n'$ is a number of factors.

To get a functional dependence of the development of plants and soil($i$) is necessary to sum the values of these quantities, i.e. denote the corresponding function after ($M$), then:

$$M_j(I') = \sum_{k=1}^{I'} \prod_{j=1}^{n'} f_j(a_j^i, x_j^i(k)),$$
where $M_i = M_i(t) = \overline{M}_i$ is the upper boundary, characteristic for the considered (i)-period.

In this case, the parameter $(ij)$ function must be unimodal, the peaks of which are achieved for some optimum value of the relevant factors, that is, $(s_{ij}(k) = s_{ij}(opt))$ [6].

The starting point for creating the model of productivity of plants and soils is the identification of a permanent characteristic connecting all without exception of factors of external environment, necessary and sufficient for the characterization of regularities of formation of a crop and soil-forming process of the natural system.

In the applied respect of particular interest and importance is the determination of the regularities of soil-forming process of the natural system. As is known, site specific, dedicated to a particular climatic zone, the value of the ratio $(\overline{R})$ is relatively constant and it is very intimately connected soil formation process and features of a soil cover.

The task of describing the requirements of plants and soil to environmental conditions can be reduced to build univariate modeling (i) - the point in time and thereafter to incorporate them into multivariate model components. For this factor take as criterion hydrothermal index $(\overline{R})$, then we can estimate the productivity of the plant - $\overline{Y} = \int \overline{R} \, d \overline{R}$ and soil - $\overline{P} = \int \overline{R} \, d \overline{R}$, which enables quantification of land productivity based on integral and criteria.

Before to make the task of describing the requirements for (i) the factor of environment (i)-time, we introduce the notions:

- $\overline{N}(\overline{R}) = Y / Y_{max}$ - degree of optimality of environmental conditions (relative productivity of plants) by the factor $\overline{R}$ where $Y_i$ is current productivity of plants ($Y_{max}$) - the potential productivity of plants, which are determined based on the level of use of solar energy.

- $\overline{P}(\overline{R}) = P / P_{max}$ - is the degree of optimal environmental conditions (relative productivity of the soil) by a factor of $\overline{R}$, where $P$ - the current productivity of the soil and $P_{max}$ - the maximum productivity of the soil, corresponding to the black earth soil productivity.

Statement of the problem of modeling the formation of plant productivity and soil analysis results from the laws of life of the plants and the soil, which suggest the possibility that changes in plant productivity and soil changes in environmental factors $(dY/d\overline{R}$ and $dP/d\overline{R}$) are proportional to the degree of optimality $\overline{N}(\overline{R})$ and $\overline{P}(\overline{R})$ variance values of the factor $(\overline{R})$ from the optimum value $(\overline{R}_{opt})$.

In fact, the greater the degree of optimality of $\overline{N}(\overline{R})$ and $\overline{P}(\overline{R})$, the greater $dY/d\overline{R}$ and $dP/d\overline{R}$, i.e. a small deviation from optimal conditions leads to a significant deviation from $Y_{max}$ and $P_{max}$. At the same time, the larger the value, the more sensitive plant improvements to the external environment and on the other hand, in accordance with the laws of nature, under optimal conditions $(\overline{R}_{opt} - \overline{R}_{opt}) = 0$, $dY/d\overline{R} = 0$ and $dP/d\overline{R} = 0$ and there is a certain point $Y_{max}$ and $P_{max}$ at $\overline{R}_{opt} = \overline{R}_{opt}$.

On the basis of the judgment equation communications $(Y$ and $P$ with $\overline{R})$ can be rewritten for (i) - time in the form of: $dY/d\overline{R} = k\overline{N}(\overline{R})(\overline{R}_{opt})$ and $dP/d\overline{R} = k\overline{P}(\overline{R})(\overline{R}_{opt})$.

Since both $Y = Y_{max} \overline{N}(\overline{R})$ and $P = P_{max} \overline{P}(\overline{R})$ it is obtained $Y_{max} = Y(\overline{R})/d\overline{R} = k\overline{N}(\overline{R})(\overline{R}_{opt})$ and $P_{max} = P(\overline{R})/d\overline{R} = k\overline{P}(\overline{R})(\overline{R}_{opt})$, where $k$ is the aspect ratio, resulting in a line of dimension on the right and left sides and characterizes the ability of self-regulation in plants and soil sub-optimal conditions.

After integrating and some transformation, we obtain the equations characterizing productivity landscapes of river basin [7]:

- **Biological productivity of vegetation:**
  $$\overline{N}(\overline{R}) = Y / Y_{max} = \exp \left[-\frac{1}{2}\left(\overline{R} - \overline{R}_{opt}\right)^2\right];$$

- **Biological productivity of the soil:**
  $$\overline{P}(\overline{R}) = P / P_{max} = \exp \left[-\frac{1}{2}\left(\overline{R} - \overline{R}_{opt}\right)^2\right],$$

where $\nu$ is effective coefficient of self-regulation.

On the basis of the biological productivity of vegetation and soil can be estimated productivity of landscapes:

$$\overline{PL}(\overline{R}) = \overline{N}(\overline{R}) \cdot \overline{P}(\overline{R}).$$

However, the productivity of landscapes is determined not only an optimal ratio of heat and moisture and the ratio of the averaged indicator values such as temperature and duration of the growing season, as well as hydrogeochemical landscape mode, which requires the need to take them into account when assessing productivity.
The models applied nature, used in agricultural meteorology and reclamation of agricultural land [8], the influence of meteorological factors on the function of the productivity of landscapes taken into account empirically - by multiplying the productivity features in optimal conditions on the impact factors [2]:

\[
\overline{PL}(\overline{R}) = \bar{S}(\overline{R}) \cdot \overline{P}(\overline{R}) \cdot K_{gr} \cdot K_s \cdot K_t \cdot K_c
\]

where \((K_{gr})\) - coefficient characterizing the length of the growing season of plants, \((K_s)\) - coefficient characterizing the hydrogeochemical landscape mode, \((K_t)\) - coefficient characterizing the temperature regime of the landscape; \((K_c)\) - the coefficient characterizing the water quality of river basins.

Each time the hydrothermal mode \((\overline{R})\) to get the possible production requires a well-defined thermal security or energy resources, that is, there is a certain optimum storage temperature range at which photosynthesis will proceed favorably under these hydrothermal conditions.

Given the symmetry of the curve in the form of the temperature coefficient \((K_t)\) [9], we put the required amount of heat \((t_o)\) as the average of the maximum and minimum amount of heat at which photosynthesis occurs more:

\[
t_p = \left[\frac{(t_1-t_o)}{(t_{opt}-t_o)}\right],
\]

where \((t)\) - the actual temperature, \((t)\) - threshold temperature for the start of photosynthesis, \((t_{opt})\) - the optimum temperature of the flow of photosynthesis.

Complex empirical relationships productivity landscapes of natural systems on temperature can be represented by the formula Y.N. Nikolsky, V.V Shabanov [10]:

\[
K_t = \left(\frac{\sum t - \sum t_{\min}}{0.5(\sum t_{\max} + \sum t_{\min}) - \sum t_{\min}}\right)
\]

where \(\Sigma '\min\) and \(\Sigma '\max\) - respectively the minimum and maximum approved temperature for photosynthesis, \((\Sigma)\) - the current total of active-temperature air for a period when the average daily temperature is above 10 °.

The influence of the length of the growing season on the productivity of landscapes, depending on the vertical zone can be described by the following formula: \(K_{gr} = T_{gr} / 365\), where \(T_{gr}\) is the duration of the growing season.

In the simulation of habitat changes of natural systems of river basins influence quality of water resources for productive landscapes can be defined by the formula [11]:

\[
K_c = \left[1 - \left(\frac{(C_1 + C_n)}{2 - C_{per}}\right)^{0.5}\right] / w,
\]

where \(K_c\) - is the coefficient of loss of productivity due to the landscape mineralization of irrigation water and groundwater; \(w\) - is the parameter that takes into account the quality of the water.

Hydrogeochemical conditions of landscapes in river basins vary depending on the vertical zone, due to the presence of toxic salts in the soil, affecting the soil-reclamation of landscapes [11]:

\[
K_{Si} = A \cdot \exp\left[-B\left(S_i^r\right)^2\right],
\]

where \(K_{Si}\) - the coefficient of yield decrease due to the presence of toxic salts in the soil, \(B\) - parameter characterizing the responsiveness of plants to toxic salts, \(A\) - parameter characterizing the type of soil salinity, \(S_i = S_i^r / S_{per}\), where \(S_i\) and \(S_{per}\) - the original and the permissible level of salinity.

Assuming that the natural system of river basins differ according to the indicator of productivity of landscape and productivity is determined by the formula \(\overline{PL}(\overline{R}) = \bar{S}(\overline{R}) \cdot \overline{P}(\overline{R}) \cdot K_{gr} \cdot K_s \cdot K_t \cdot K_c\), in this model uses the change of the integral index of productivity as a criterion the position of the boundaries of the natural systems.

Thus, the productivity of agricultural land should be understood comprehensive characterization of the landscape, which is a bioenergetic natural resource system, is expressed in the productivity of plants and soil.

Mathematical Modeling of the Environmental Assessment of the Productivity of Landscapes on the Basis of Bio-Energy Resources of the Natural System: The problem of natural and environmental assessment of the transformation of the natural system in the modern era is recognized as one of the topical problems of natural science. Therefore, in the future transformation projects or reconstruction of damaged natural systems technologically possible should be provided for all the positive and negative impact of expected changes in natural relationship, where development pressure on the natural system in comparison with the natural very high. Hence the problem of rational use of natural resources and protection of the natural system of course requires that the conversion of the natural system were truly complex and compensation based on ecological and economic criteria.
Table 1: Scale of assessment of the ecological productivity of landscapes

<table>
<thead>
<tr>
<th>Index</th>
<th>( P_{\text{sc}} )</th>
<th>( K_{\text{sc}} )</th>
<th>( \overline{P}(\overline{K}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>&lt;0.01</td>
<td>&lt;0.10</td>
<td>&lt;0.10</td>
</tr>
<tr>
<td>Low</td>
<td>0.01-0.02</td>
<td>0.10-0.20</td>
<td>0.10-0.20</td>
</tr>
<tr>
<td>Lowered</td>
<td>0.02-0.030</td>
<td>0.20-0.30</td>
<td>0.20-0.30</td>
</tr>
<tr>
<td>Average</td>
<td>0.03-0.04</td>
<td>0.30-0.40</td>
<td>0.30-0.40</td>
</tr>
<tr>
<td>Above average</td>
<td>0.04-0.05</td>
<td>0.40-0.50</td>
<td>0.40-0.50</td>
</tr>
<tr>
<td>Increased</td>
<td>0.05-0.06</td>
<td>0.50-0.60</td>
<td>0.50-0.60</td>
</tr>
<tr>
<td>High</td>
<td>0.06-0.07</td>
<td>0.60-0.80</td>
<td>0.60-0.80</td>
</tr>
<tr>
<td>Very high</td>
<td>&gt;0.08</td>
<td>&gt;0.80</td>
<td>&gt;0.80</td>
</tr>
</tbody>
</table>

To evaluate the efficiency of PAR crops can apply utilization of bioenergy plants \( K_{\text{sc}} = R \cdot \eta_{\text{f}} / 100 \cdot BP \), where \( BP \) - Bio-energetic potential of plants, 2,500 kcal / (m² year), \( \eta_{\text{f}} \) utilization of free energy, which under natural conditions is 0.005.

Evaluation of plant moisture is carried out by a factor of natural moisture landscapes \( K = O_{\text{p}} / E_{\text{a}} \), where \( O_{\text{p}} \) - precipitation, mm, \( E_{\text{a}} \) - evaporation, mm.

For the integrated assessment bioecological productivity can use a set of utilization of bioenergy plants \( K_{\text{sc}} \) and the efficiency of precipitation \( K_{\text{w}} \), that is, the productivity index bioecological landscapes: \( P_{\text{sc}} = K_{\text{sc}} \cdot K_{\text{w}} \).

Table 2: Environmental assessment of the productivity of landscapes of the river basin Chu

<table>
<thead>
<tr>
<th>Weather station</th>
<th>( H, \text{m} )</th>
<th>( R, \text{kJ/m}^2/\text{s} )</th>
<th>( \overline{R} )</th>
<th>( Y, \text{m}^2/\text{a} )</th>
<th>( K_{\text{sc}} )</th>
<th>( \overline{P}(\overline{K}) )</th>
<th>( P_{\text{sc}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Mountain class landscapes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuya-Ashu</td>
<td>3090</td>
<td>88.2</td>
<td>0.52</td>
<td>1.31</td>
<td>0.4130</td>
<td>0.05</td>
<td>0.150</td>
</tr>
<tr>
<td>Alaaracha</td>
<td>2945</td>
<td>96.0</td>
<td>0.73</td>
<td>2.36</td>
<td>0.6400</td>
<td>0.07</td>
<td>0.069</td>
</tr>
<tr>
<td>Karakudzhar</td>
<td>2800</td>
<td>100.5</td>
<td>1.16</td>
<td>2.80</td>
<td>0.7700</td>
<td>0.12</td>
<td>0.043</td>
</tr>
<tr>
<td>Piedmont subclass landscapes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basyk</td>
<td>1579</td>
<td>126.9</td>
<td>1.03</td>
<td>4.15</td>
<td>0.9600</td>
<td>0.48</td>
<td>0.053</td>
</tr>
<tr>
<td>Shamsy</td>
<td>1556</td>
<td>143.1</td>
<td>1.52</td>
<td>4.51</td>
<td>0.5170</td>
<td>0.52</td>
<td>0.036</td>
</tr>
<tr>
<td>Kegety</td>
<td>1400</td>
<td>146.0</td>
<td>1.61</td>
<td>6.25</td>
<td>0.4430</td>
<td>0.46</td>
<td>0.033</td>
</tr>
<tr>
<td>Piedmont -plain subclass landscapes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tokmak</td>
<td>818</td>
<td>182.8</td>
<td>3.10</td>
<td>4.65</td>
<td>0.1210</td>
<td>0.28</td>
<td>0.042</td>
</tr>
<tr>
<td>Bishkek</td>
<td>756</td>
<td>200.0</td>
<td>2.10</td>
<td>4.51</td>
<td>0.2860</td>
<td>0.28</td>
<td>0.039</td>
</tr>
<tr>
<td>Merke</td>
<td>703</td>
<td>192.1</td>
<td>3.40</td>
<td>4.15</td>
<td>0.0960</td>
<td>0.15</td>
<td>0.027</td>
</tr>
<tr>
<td>Kulan</td>
<td>683</td>
<td>196.0</td>
<td>4.80</td>
<td>4.15</td>
<td>0.0350</td>
<td>0.15</td>
<td>0.020</td>
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<tr>
<td>Plain class landscapes</td>
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</tr>
<tr>
<td>Umbet</td>
<td>512</td>
<td>207.6</td>
<td>7.10</td>
<td>2.80</td>
<td>0.0080</td>
<td>0.07</td>
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<td>Sholakurgan</td>
<td>481</td>
<td>218.1</td>
<td>12.6</td>
<td>1.51</td>
<td>0.0006</td>
<td>0.10</td>
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<td>Tolebi</td>
<td>456</td>
<td>207.6</td>
<td>7.10</td>
<td>1.42</td>
<td>0.0080</td>
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<td>0.013</td>
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<tr>
<td>Monkum</td>
<td>351</td>
<td>200.0</td>
<td>7.70</td>
<td>1.31</td>
<td>0.0075</td>
<td>0.06</td>
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<tr>
<td>Baikadam</td>
<td>338</td>
<td>211.5</td>
<td>9.10</td>
<td>2.80</td>
<td>0.0023</td>
<td>0.05</td>
<td>0.013</td>
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<tr>
<td>Sozak</td>
<td>317</td>
<td>211.4</td>
<td>10.5</td>
<td>2.70</td>
<td>0.0011</td>
<td>0.04</td>
<td>0.012</td>
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<tr>
<td>Ulambel</td>
<td>266</td>
<td>203.7</td>
<td>10.0</td>
<td>2.70</td>
<td>0.0014</td>
<td>0.04</td>
<td>0.010</td>
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<tr>
<td>Kamkaly-Col</td>
<td>207</td>
<td>219.2</td>
<td>11.0</td>
<td>2.70</td>
<td>0.0008</td>
<td>0.04</td>
<td>0.013</td>
</tr>
</tbody>
</table>

To comply with a common approach to the assessment of efficiency of landscapes in Table 1 shows the scale of assessment of the ecological productivity of the landscape.

RESULTS AND DISCUSSION

Calculation of environmental assessment productivity agrolandscapes on the basis of the proposed methodological approach is made for the river basin Chu according to long-term materials 21 weather station (Table 2).
As can be seen from Table 2, using the «drought index» \( \overline{\pi} \), characterizing the biological process in natural systems, you can assess the efficiency of landscapes of river basins as \( \overline{\pi}(\overline{v}) \), \( P_v \) and \( K_v \), depending on the elevation of the surface of the earth \( H \) Chu river basin, which has the same pattern.

Comparison of accuracy and similarities of the proposed methods of environmental assessment of productivity of natural environmental components to the analog of the curve \( Y \), c/ha, obtained on the basis of the experimental data show that the developed model of the environmental assessment productivity landscapes, allows to give to, first, quantitative values of qualitative changes of habitats; secondly, modeling transformation of natural systems to climate change; third, landscape-ecological zoning of the natural systems of river basins.

Thus, consideration of the problems of assessment of bioenergy efficiency of water and land resources of river basins allows you to define productivity not only landscapes and agro-landscapes in conditions of anthropogenic impact on the natural system.

The bioenergy assessment of the efficiency of cultivation of agricultural crops at the present anthropogenic pressure on the natural environment should include not only economic criteria dictated by economic needs, but also environmental, excluding the deterioration of the natural environment or providing for its recovery, if the environment is compromised or lost stability as a result of high anthropogenic pressures.

REFERENCES