ISSN 1875-3728, Geography and Natural Resources, 2015, Vol. 36, No. 4, pp. 335-340. © Pleiades Publishing, Ltd., 2015.
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Assessing Agricultural Impact on Natural Systems: Theoretical and Methodological Approaches

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Received November 13, 2014

Abstract—We carried out an analytical summary and a systematization of the national and international methodological approaches in assessing impacts of agriculture on environment. The most noteworthy among them are the assessments of life cycle, ecological risks and threshold impacts as well as energy-ecological strategy (including Emergy). We give an outline of the most demanded (for practical purposes) foreign systems of indicators and analyze the features peculiar to them. We suggest our own technique for assessing the influence of agriculture to be used in strategic governance of nature management. It includes diagnosing the specific character and selecting the indicators, assessing the degree of impact and of its deviation from the optimal level, correlating the value of agricultural pressure with the landscape structure of the study area on the basis of landscape (geosystem) approach, and analyzing the positive and negative consequences for natural systems. A set of indicators is recommended for the steppe and forest-steppe zones of Western Siberia, which depends on the scope of research and the specialization of agriculture that takes into consideration the consequences of impacts on environment. This technique was tested for the agrarian-oriented and agrarian-recreational territories of Altai krai to show high performance in territorial planning for purposes of balanced agricultural nature management in so far as it can be used for strategic governance of any region.

DOI: 10.1134/S1875372815040034

Keywords: agriculture, critical load, indicators of impacts, integral assessment, consequences of impacts.

FORMULATION OF THE PROBLEM

Strategic documents of territorial development that are being developed and approved for each region of the Russian Federation do not always take into consideration in full measure the ecological requirements to be observed for the preservation of natural systems in conditions of socioeconomic and natural/ecological transformations. This is especially true in regard to assessments of the present status of the environment, the degree of anthropogenic impact on natural systems, and forecasts of their changes. Governance of nature management is based on dealing with these problems, especially for regions where the strategic directions of development involve the use of a territory's natural-resource potential.

Of particular current importance for agrarian-oriented territories is becoming the analysis of agricultural impacts which would make it possible to appropriately assess the existing load on natural systems, establish the environmentally acceptable structure of agricultural lands, and to maintain the parameters of such a load within allowable ecological limits for purposes of the preservation of soil fertility and the territorial ecological equilibrium.

Since the early 1970s an intensification of agricultural production across the globe has led to an enhancement in the negative ecological processes in natural systems and, hence, triggered an increase in the number of scientific investigations dealing with assessments of agricultural impacts on the environment [1–3]. Forecasts made by scientists concerning a further population upsurge worldwide and the resulting increase in the demand for foodstuffs indicate that the degree of agricultural influence on natural systems will only be increasing; therefore, to devise methods for such an assessment for purposes of sustainable development still remains a challenging issue.

THEORETICAL AND METHODOLOGICAL APPROACHES TO THE STUDY OF AGRICULTURAL IMPACTS ON THE ENVIRONMENT

In a generalized form, agricultural impact is taken to mean the influence of agricultural activity causing changes in the properties and components of the natural system which would lead to disturbances of the performance of its ecological and socioeconomic functions.

In this case, according to a more precise definition proposed by V.K. Shitikov and collaborators [4], the very term 'impact' has a specific meaning in the context of ecological assessment. In the Russian language, the word 'impact' is often understood as "what is acting on", and the term does not cover the consequences of this event or process. In the English language, however, especially in terminology related to Environmental Impact Assessment, this notion covers "what is acting on" as well as "what occurs as a result", i.e. the consequences of the action of a set of factors. And this latter definition is used as the basis in this paper.

Analysis of the types of agricultural impacts [5] shows that the variety in their entirety can be combined into the following four groups: extraction of substances; transformation of components or processes of natural systems; introduction of substances, and construction of engineering and technogenic facilities.

The specific character of agricultural impacts implies their spread over large areas, causing changes and radical restructuring of all components of natural systems, especially in the case of an intensification of agrarian production. Furthermore, the response of natural systems to agricultural impacts is, to a significant degree, differentiated because of the difference in the character and intensity of activity itself [1, 6, 7].

To date, several approaches to the theoretical and methodological substantiation of impact assessment of agriculture on the environment are known internationally.

1. Life Cycle Assessment, LCA, is a method of determining the environmental impact from production, the utilization and disposal of the product or services. Originally, it was conceived and developed for the study into the influence of industrial production and came into use in the analysis of agricultural impacts in the field of plant-growing [8] as well as of livestock farming [9, 10]. The Eco-indicator 95 program and its updated version, Eco-indicator 99, are used as the tools for life cycle assessment [11].

2. The ecological energy approach is based on quantitative assessments of different energy flows in the agricultural system in order to reveal and study the structural and functional relationships between its components as well as investigate, within the dynamical context, the influence of various energy sources on the functioning of agro-ecosystems [12–15].

Inputs of anthropogenic energy to the agro-ecosystem are treated not only as the factor for raising productivity of agricultural crops but also as an additional load on its components, leading to a decrease in natural soil fertility, nonproductive losses of matter and energy, and to pollution. In other countries, a modified version of this approach, the Emergy method, enjoys popularity; it is based on the view that any object has a definite amount of primary solar energy used for its creation [14, 16, 17].

3. Assessment and mapping of ecological risks related, in particular, to agricultural production implies analyzing the occurrence probability of negative events and processes in natural systems as a result of anthropogenic activity for the purpose of developing and implementing measures for mediating and preventing the threat of formation and consequences of dangerous ecological situations [18–21].

4. Assessment of critical loads on the environment [22–24] seeks to define ecological standards (restrictions) of an allowable agricultural load. Most authors (following Yu.A. Izrael' [25]) argue that an allowable load should imply such a load where any deviation from a normal state of the system does not exceed the natural changes and does not lead to a deterioration of the environmental quality.

INDICATORS AND METHODS

The available methods of determining the agricultural impact largely imply calculating specific indicators (such as the livestock number or fertilizers per unit of area), which is of practical importance when comparing with maximum allowable values (MAC of pollutants, rate of grazing, norms of forest cover, etc.) as established experimentally. Such an approach at the present state of the art in science is justified and effective provided that the specific character of the study territory is necessarily taken into consideration.

Nevertheless, the scientific community has recently became aware that some single method would not suffice so that there emerged comprehensive and integral approaches to assessing agricultural impacts [26–28]. Among them, research efforts are worthy of notice, which compare traditional and alternative agricultural practices from the perspective of their influence on the environment [10, 16]; test different agro-ecological indicators for analyzing potential impacts of agricultural technologies [2], and use databases and models based on mathematical and linear programming, such as CAPRI (Common Agricultural Policy Regionalised Impact) [29].

In connection with a large number of types of agricultural activity causing different-scale and different-intensity changes in landscapes as well as with the diversity and complexity of natural systems, there are rather many indicators of agricultural impact on them. Following are the indicators most known abroad.

1. "Pressure-State-Response", PSR is a currently widely used group of ecological indicators as well as its modifications (DSR, and DPSIR), including for agricultural purposes: Land Quality Indicators (LQI); ELISA, and others [30–32]. It includes indicators of direct (stress) and indirect (background) impact on the environment. It is also stated that human activity involves an impact which can cause changes in the state of environment, and society (the nation state) then responds in order to prevent, reduce or minimize this impact via ecologo-economic and political programs.

2. Agro-ecological indicators (AEIs) is a set of 28 indicators adopted by the European Commission for monitoring integration of environmental issues in the general agricultural policy of the European Union. Various systems of aerological indicators were also

developed for monitoring the condition of natural resources, the load and risks for the environment as a result of the activity of agricultural producers at the national (IRENA) as well as the local (farms) levels [33, 34].

3. Indicators of the impact on agricultural landscapes reflecting their various characteristics: the structure (types of land use, vegetation cover, mosaic pattern, and cultural features); functions (ecosystems-specific, recreational, and environment-reproducing); significance; management (of the cultural heritage, and farms), etc. [35].

4. The Environmental Monitoring and Assessment Program (EMAP) was run by the United States Environmental Protection Agency (EPA) to advance the science of ecological monitoring and ecological risk assessment, guide national monitoring with improved scientific understanding of ecosystem integrity and dynamics, and demonstrate multi-agency monitoring through large regional projects as well as to develop indicators to monitor the condition of ecological resources. EMAP also investigated designs that addressed the acquisition, aggregation, and analysis of multiscale and multitier data [36].

Based on this, it is of considerable current importance to look for such indicators which would most thoroughly reflect the degree of impact of agricultural practices on natural systems and (and this is equally important) are accessible for gathering and processing to a wide range of specialists.

To assess the ecological state of natural systems, i.e. the consequences of agricultural practices, most commonly uses the set of indicators ranked according to several classes: optimal, allowable, critical, and disastrous (see table).

Based on analyzing the aforementioned scientific approaches and groups of indicators, we developed the technique for assessing agricultural impacts on natural systems for purposes of the strategic governance of agrarian nature management. The technique was tested

Criteria of ecological status of natural systems as a result of agricultural impact

Assessment indicators	Classes of ecological status			
	norm	risk	crisis	disaster
Soil fertility, % of the potential	> 85	85–60	60–25	< 25
Humus content, % of the initial	> 90	90–70	70–30	< 30
Area of secondary salinization, %	< 5	5–20	20–50	> 50
Degree of truncation of soil horizons		Trunc. hor. A1 or 0.5 hor. A	Trunc. hor. A and partly AB	Trunc. hor. A and B
Area of wind erosion (fully deflated soils), %	< 5	5–20	20–40	> 40
Decrease in soil profile thickness (A + B), % of the initial		< 3	3–50	> 50
Decrease in humus reserves in soil profile (A + B), % of the initial		< 10	10–40	> 40
Increase in the area of moderately and strongly eroded soils, % in a year		< 1	1–5	> 5
Area of natural fodder fields removed from land use (bare of vegetation), % of total area		< 10	10–50	> 50
Projective cover of pasture vegetation, % of the zonal	> 90	70–90	50–70	< 50
Growth rate o the area of degraded pastures, % in a year		< 3	3–5	> 5
Rate of decrease in organic matter content in soil, % in a year		< 0.5	0.5–7	> 7
Growth rate of the area of saline soils, % in a year	—	< 1	1–5	> 5
Growth rate of the area of eroded soils, % in a year		< 0.5	0.5–5	> 5

Note. Compiled according to [37, 38], data from OAO AltaiNiiGiprozem and these authors' observations. "–" – no data. The indicators for the Smolenskii district are highlighted in grey.

against agrarian-oriented territories in the steppe (the basins of the Burla river and Lake Kulunda) and piedmont (Smolenskii district) zones of Altai krai, showing a high practical significance in the development of territorial planning schemes [39, 40]. The assessment technique consists of the four main stages: 1) diagnostics of the specific character of agricultural impacts on the natural systems of the study territory, and selection of a group of indicators; 2) determination of the degree of agricultural impact and its deviation from optimal ecological parameters; 3) correlation of the indicators of the degree of agricultural load with the landscape structure of the study territory on the basis of landscape (geosystems) approach, and 4) assessment of positive and/or negative consequences of agricultural impacts on natural systems.

The analysis of the specific character of the agricultural impact on natural systems in the agrarian-oriented areas of the West Siberian Plain showed that the main consequences of such an impact include the irrational pattern of land uses, with the share of arable lands predominating; a high livestock-breeding load on pasture fields caused not so much by a large livestock population as by its high concentration in the vicinities of human settlements, and by nonobservance of the pasture rotation; an almost total absence of environmentally sustainable agricultural practices; application of organic and mineral fertilizers, insufficient for replenishment of the deficit of nutrients, and pollution of water resources by livestock-breeding wastes.

In this connection, it is worthwhile to consider the following three groups of indicators to be the most indicative for assessing the agricultural load on steppe and forest-steppe natural systems of the West Siberian Plain:

– characterizing the impact of plant-growing practices: the share of natural (not transformed and little transformed by humans) landscapes in the total area (%); the share of arable lands in the area of agricultural fields (%); the share of perennial grasses in the area of the arable land (%); the share of fodder fields in the area of agricultural lands (%); the share of forests in the total area of the territory (%); the share of irrigated lands in the area of agricultural lands (%); the amount of organic and mineral fertilizers applied per ha of the arable land; the amount of pesticides per ha of the arable land, and the number of agricultural machinery and equipment per 100 ha of agricultural lands;

– characterizing the impact of livestock husbandry: the livestock number per 100 ha of natural fodder fields; the number of specialized livestock breeding complexes, and the volume of livestock-breeding waste waters and output of manure, and

– characterizing the pattern of rural population distribution: the share of residential territories in the total area, rural population density, and the volume of domestic sewage.

The necessary indicators are collected at the level of a municipal district in the context of agricultural enterprises. This is due to the fact that the district level regulation is the most important in the governance of nature management: it shows most clearly the interrelationship between the degree of impact and its consequences for natural systems, and renders concrete the area of application of nature-conservancy and recultivation measures. It is also important that within the framework of a single district the norms of state of landscapes at the same hierarchical level are usually identical (because of the similarity of the natural-climatic conditions, the species composition of the biogeocenosis, and other factors).

The second, third and fourth stages of practical implementation of the suggested technique were tested on the territory of the Smolenskii district of Altai krai.

CONCLUSIONS

The analysis of available theoretical and methodological techniques for assessing agricultural impacts on natural systems showed that over the past several decades the scientific community has shown the tendency toward developing and implementing integral methods and approaches, including with the use of different program models.

Selection of a group of indicators depends, to a significant extent, on the scope of research and the specialization of agriculture; it is aimed at achieving accessibility of the indicators to a large range of specialists, their multipurpose character and informativity, and the possibility of monitoring over the course of several years of observations.

Assessment of agricultural impacts on natural systems is of particular current importance for strategic governance of nature management of agrarian-oriented areas in the interests of sustainable development.

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