OPEN ACCESS
International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-4, April 2019

Accounting and Evaluating Soil Fertility to Form Information Systems for Land Resource Management

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Abstract*: *The regulatory and methodological basis for monitoring agricultural land is formed without taking into account differences of fertility parameters required to manage land at various system levels. The applied set of parameters, the method of defining and presenting them during agrochemical surveys as an information base for monitoring agricultural lands and the Federal State Information System Functional Subsystem "Electronic Atlas of Agricultural Lands" (the FSIS FS EAAL) founded on its basis do not comply with the modern functions of the state and municipal land management.

The concept of standard yield for the land evaluation that uses a systematic approach to evaluating soil fertility in land management has been formalized. The results of evaluating the error in determining the rental income when using the actual rather than standard values of productivity and costs have been given.

Index Terms*: *management, model, monitoring, rental in-come, resource potential, soil phase, standard yield, system level.

I. INTRODUCTION

One of the conditions for the efficient use of land in agricultural production and the prevention of the degradation of agro-ecosystems is the availability of reliable information on the indicators of the land quality and adequate models of their agro-ecological and economic evaluation that is available for including in management mechanisms. Only based on analyzing decision-making algorithms in the land management systems themselves, it is possible to substantiate requirements for the formed land information systems (LIS).

The difference in the target functions of land management at various system (spatial) levels implies the peculiarities of forming the model and the composition of soil fertility indicators. Soil fertility parameters at the regional and municipal management levels should provide mass economic evaluation and zoning of the territory, taking into account the suitability of the soil for agricultural use.

The function of accounting the characteristics of the qualitative state of agricultural land is laid upon the FSIS FS EAAL. The information basis for it is formed by the current agrochemical surveys whose parameters and the form of the graphical representation do not correspond to the modern functions of state and municipal administration.

The **purpose of the work** is to substantiate the requirements to the soil fertility model when forming LIS to fulfill modern land management functions at the municipal and regional levels.

II. PROPOSED METHODOLOGY

A. Problem Aspects In The Regulation Of Soil Fertility Accounting

The technological basis for including information and scientific knowledge about the qualitative characteristics of the soil, the conditions for the reproduction of their fertility in the land management system is the functioning of state LIS. Their efficiency directly depends on the LIS ability to ensure the fulfillment of management functions in terms of the composition (completeness) of parameters and the quality of information (accuracy, speed), and the form of presentation (level of generalization/discrediting).

Nowadays, a real estate cadastre functions as a LIS. It is based on the integration of the real estate cadastre and monitoring of agricultural land – the FSIS FS EAAL. In terms of land, the real estate cadastre specifies neither its qualitative characteristics nor type. The function of accounting the characteristics of using the qualitative state of agricultural land is the responsibility of the FSIS FS EAAL. Filling the system with the indicators characterizing the qualitative state is the responsibility of federal state budget institutions of the agrochemical service and agricultural radiology subordinated to the Ministry of Agriculture of Russia, in accordance with the state tasks reported according to the established procedure. How do the normative documents regulate the primary spatial object of soil fertility? "Procedure of state registration of indicators ..." [1] approved by Order of the Ministry of Agriculture of Russia No. 150 dated May 4, 2010 states that fertility indicators are taken into account for each land plot that is homogeneous by the **soil type**, occupied by uniform vegetation in the context of the agricultural land.

Manuscript published on 30 April 2019.
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When establishing the FSIS FS EAAL by order of the Ministry of Agriculture of Russia No. 37-p dated June 21, 2017 [2], the section "Structure and composition of information of the FSIS FS EAAL" indicates that the characteristics of each contour of agricultural land should include the information about **the types of soil differences**.

According to the classification of soils, a soil type is the highest unit of soil mapping. For example, chernozem as a type of soil is classified into subtypes (typical, ordinary, southern chernozem, etc.). In its turn, depending on the thickness of the humus horizon, the humus content, particle size distribution, manifestations of negative processes are divided into classification units of the lower level (genera, species, phases). Consequently, the same type of soil can be characterized by a great number of soil characteristics that cause rather considerable differences in the level of potential fertility of soil phases. In large farms, one type of soil may be represented by several dozens of soil differences, and within one working area of agricultural land, the soil cover may include several soil phases.

At the same time, the soil classification does not include the notion "type of soil phase". There is a notion of soil type as the upper hierarchical classification unit, and the notion of soil phase as the smallest unit of soil mapping. The soil phase as an individual object of soil mapping is an individually defined object for the quantitative measurement of the qualitative characteristics of the land in terms of the fertility level. Consequently, the quantitative indicator of fertility of both individual agricultural plots and land use in general can only be defined on the basis of individual fertility evaluations represented on site of individual contours of soil phases.

Orders and instructions of the Ministry of Agriculture of Russia [1, 2, 3] set rather many quality parameters for monitoring agricultural land. At the same time, there is no differentiation in the set of parameters that should be the subject of area surveys to characterize all sites, and the ones found only at special polygons. In practice, field surveys define only agrochemical indicators (availability of mineral nutrients, acidity), the content of organic matter in the topsoil, and contamination with heavy metals. At the same time, the results of definitions are not "tied" to a certain soil. This is an averaged characteristic of an elementary area (EA) as a primary object of surveys, the boundaries of which are not connected to the boundaries of soil phases, but are determined from the requirements to the distribution of the surveyed lands (mainly arable lands) according to the established standards (10, 20, 40 ha) depending on applying phosphate fertilizers on the farm [4]. Under the current doses of using fertilizers on farms, the maximum sizes of EA are established for soil and climatic zones – 20 – 40 hectares.

III. RESULT ANALYSIS

A. Analyzing the Compliance of Agrochemical Surveys' Methodology with The Purposes of Soil Fertility Evaluation

Using the land of the Povolzhye Academic and Research Production Association located in the Engels District of the Saratov Region, the results of agrochemical surveys were analyzed in terms of quantity according to the accepted sampling method to characterize the fertility indicators of certain soil phases. Based on the MapInfo program complex, a number of operations were carried out on geodetic referencing and correlation of materials of agrochemical and soil surveys (Fig. 1). The dots show the routes of moves to select soil samples of the agrochemical survey in elementary areas.

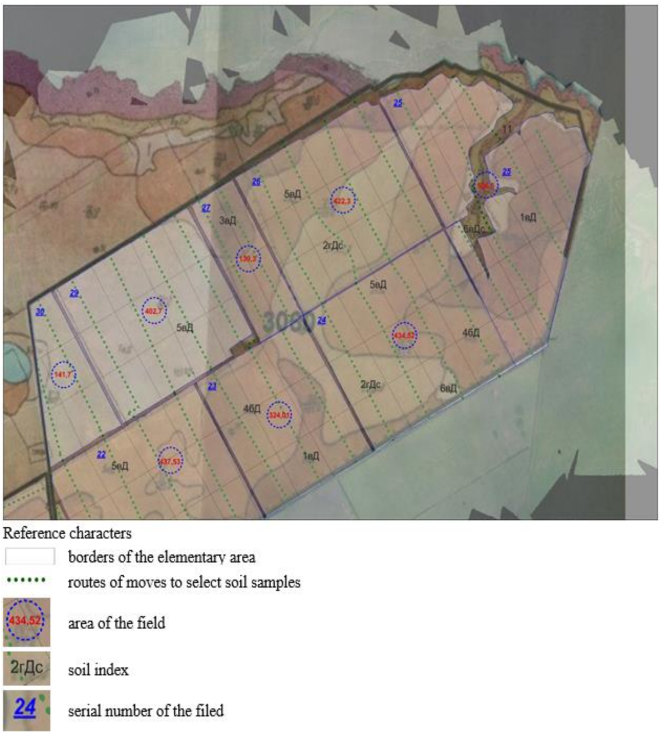

Fig. 1. Example of Correlating the Boundaries of EA of Agrochemical Surveys and Contours of Soil Phases

The parameters on the allocation of soils on certain EA and the move length for selecting samples of certain types of soil (Table 1) were calculated. The second parameter measures the proportion of a certain soil sample to the one of its area in the EA. Only 35.8 % of the area complies with the requirement to the EA uniformity by the soil cover (when 90 % and more of the EA is the same soil phase). Approximately the same proportion of the area under survey is represented by the EA where the predominant soil occupies from 70 to 90 %. At the same time, about one third of the EA is covered with heterogeneous soil where the predominant soil is less than 70 % of the EA.

Table 1. Characteristics of the Soil Cover Uniformity in EA of the Agrochemical Survey

Parameters and indicators	Groups of EA by the uniformity of the soil cover, %			
Maximum proportion of the EA occupied by one type of soil, %	100	90 – 100	90 – 70	<70
The number of EA in the group	31	11	42	29

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Proportion of the surveyed area occupied by the group according to uniformity, %	27.2	9.6	34.6	28.6

There is no use in determining the organic matter in the arable layer of soils (the only parameter of the agrochemical survey used in a comparative evaluation of the potential soil fertility to make agro-ecological and economic assessment of land) without strict identification of the sample belonging to a certain soil phase. For obvious reasons the economic assessment of lands (the dependence of soil parameters on the conditions of their use) is based not on individual, but on averaged characteristics of the soil phase in the land area under evaluation.

The method of sampling soil during agrochemical surveys, when the boundaries and area of the EA are established according to the requirements to its certain area and minimization of the time spent on profiling the plots [4], causes the uncertainty of the boundaries, allocated gradations of nutrients availability and soil humus content. In this case, the boundaries of the availability gradations are predetermined by the algorithm for planning the location of elementary sites rather than by a complex of natural (soil boundaries) and economic factors. Such mechanism for establishing boundaries can be considered acceptable for the differentiation of fertilizer doses, but only in case the dimensions of the EA are less than 20 – 40 ha.

IV. SYSTEMATIC APPROACH TO THE METHODOLOGY FOR SOIL FERTILITY EVALUATION

Fundamental changes are needed not only in the organization of surveys to establish the characteristics of the qualitative state of agricultural lands, but also in the very methodology for evaluating and accounting soil fertility in the land management system. Scientific publications thoroughly consider and analyze the very notion of fertility, the current methods for its quantitative measurement based on various soil and agro-climatic characteristics, as well as the classification of models according to the complexity and accuracy of describing agronomically considerable processes [5-9]. However, it is necessary to note that one, the most important classification characteristic of the fertility model the concept of a systematic approach to the description of processes in complex systems is associated with, has not yet been considered. It is mandatory to take into account the features of various system levels. Land management tasks based on evaluating and accounting soil fertility, the used behavioral models and the parameters of the object state will vary depending on the system level where the control is exercised, which include at least four levels: field (working area of the land), soil cover in an agricultural enterprise, land resources in the administrative region, and land resources in the region (Table 2).

Land management at any structural level implies the substantiation of a criterion for the efficiency of control actions that measures the results and costs. At all levels, the productivity of land is a parameter that measures the result of management. At the field and farm level, productivity directly determines the net income. At a higher level, the rental income is functionally linked to the value of regulatory productivity. Its capitalization establishes the land resources value that is an indispensable element of implementing the economic management mechanism. In its essence, the evaluation of agricultural land is to bring heterogeneity characteristics of the evaluated land plot, macro- and microeconomic conditions of its use into the parameters of productivity (production value) and production costs.

At the first glance, in order to fulfill management functions at all spatial levels, it is necessary to have the same set of soil and agro-climatic parameters that allow determining crop yields. However, it is not. Crop yields are predetermined both by natural factors (provision of the territory with water and thermal resources, soil properties) and a technology (level of production intensification) that means a rather wide range of control actions from the selection of varieties of the same crops, food management to the ways to control weeds and diseases. Depending on the farming crop, the yield of crops may differ by 50 – 100 % in different farms with the same agricultural production characteristics of land [6, 10]. In order to exclude the impact of differences in using the agro-resource potential of lands on different farms, it is necessary to use standard rather than actual yield to evaluate the land [9, 11].

Table 2. Structuring Land Management Tasks at Different Spatial Levels Based on Soil Fertility Parameters

Spatial level	Problems to solve	Criteria of economic efficiency
1. Field (working area)	Management of bioproduction processes **under stable indicators of the soil cover of the working area** by using technological methods of soil treatment, fertilization, control of diseases and pests of agricultural crops.	The maximum net income obtained from 1 ha of the arable land while maintaining soil fertility.

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2. Land use (farm)	On-farm organization of the territory that ensures the compliance of the **characteristics related to the soil cover of the land used**, topography, transport accessibility with the type of land and crop rotation, substantiation of measures for maintaining soil fertility, and carrying out reclamation activities.	The maximum net income obtained from 1 ha of agricultural land used while maintaining soil fertility, the achieved level of land reclamation.
3. Municipal entity (district)	Zoning of the territory, taking into account the **quality of land resources**, the development and implementation of municipal programs on using and protecting lands, management of lands owned by municipalities, regulation of the market redistribution of lands, taxation, control over the condition and use of land funds.	Optimization of the allocation and use of the land fund by categories, lands and forms of ownership contributing to the growth of the market value of land resources as a base for the increase in land payments made to the local budget.
4. Subject of the Russian Federation	Developing a regulatory framework for the land use and protection, regulating market redistribution, cadastral evaluation, ensuring food independence, creating a database on the quality characteristics of the land fund, zoning the territory, and monitoring the state and use of the land fund.	Maximum profitability of the agricultural production and the market value of land resources, their investment attractiveness. Ensuring reproductive processes of agricultural land use, reducing the burden on the regional budget to support the budgets of municipalities.

The formalization of the concept "standard yield" is a mandatory condition for the reproducibility and unambiguity of the results of evaluating agricultural land. The very concept of a standard as an economic category, as mandatory conditions for establishing the numerical values of the standard parameter, implies the need to take into account the achievements of the scientific and technological progress, the rational use of all types of resources and the improvement of production management. However, in this case, the standard is not only a quantitative measure of the cost of living and materialized labor per unit of output, but also reflects social requirements to the results of activities, and characterizes the required level of the resource efficiency.

Taking into account the above provisions that reveal the very concept of "a standard", the following definition of the standard yield for the purpose of land evaluation is offered: "**Standard yield is the yield limited by uncontrolled natural resources of the territory's biological productivity (heat and moisture) and the averaged soil characteristics in the land under evaluation that are included in soil evaluation characteristics under the fixed (standard) level of using land in crop production".**

At the same time the offered approach to establishing a standard yield as an indicator of resource-provided yield (only unmanaged natural resources are meant) implies an appropriate level of costs in managed resources that ensure the possibility to implement crop productivity limited by natural resources. Managed resources include not only doses of organic and mineral fertilizers, calculated on a basis of the need to maintain an equilibrium balance of mineral nutrition elements and organic matter of the soil. This includes also the availability of equipment for the timely execution of technological operations whose market value is used to calculate the costs for repair, maintenance and depreciation, the cost of human resources reproduction, and the cost of all resources provided by the standard technological map: seeds, electricity, and chemicals. The scheme of forming a crop yield model and the parameters used in it will differ depending on the system level of management (Fig. 2).

During the economic evaluation considered as an element of land management at a higher level than the field, the provision of soils with elements of mineral nutrition that depends on the doses of organic and mineral fertilizers acts as a cost-forming rather than crop-forming factor of production. Whereas, in bioprocessing management models at the field level (intermittent arrows in the figure), fertilizer doses are considered as factors for managing the reserves of mineral nutrition elements and the agro-physical properties of the soil with which optimal food and water-air conditions of the root layer of soils, and consequently, yield are associated with. This is a fundamental difference in the way the agrochemical factor is taken into account when forecasting the yield in the land evaluation system at various spatial levels of management.

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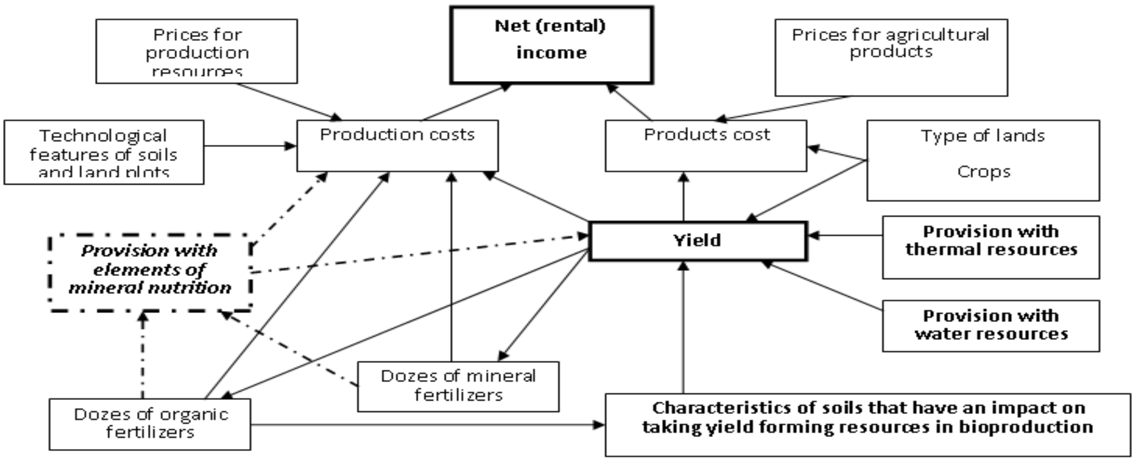

Fig. 2. Scheme of Interaction of Yields' Forming Resources

When Evaluating the Integral Indicator of Land Management Efficiency In the previously published paper [11], the authors showed that out of all models that can be implemented on the basis of the information about the qualitative characteristics of the soil that is available for the mass evaluation, only the model based on the interregional evaluation of the agro-resource potential of the territory [12] makes it possible to determine the standard yield whose value corresponds to this concept. It is possible to certificate agricultural land for mass evaluation and zoning of the territory according to the soil suitability parameters for agricultural use with the minimum cost based on the materials of the intrafarm land evaluation carried out in 1990 – 1991. All working plots of the arable land of former collective and state farms obtained a qualitative characteristic in the form of a soil bonitet point, and plots of natural forage lands – in the form of their productivity evaluation. To determine the soil bonitet point and the standard yield, almost the same set of soil characteristics is used. For this reason, it is quite natural that there is a very close regression connection (with the coefficients of determination 0.96 – 0.97) of the bonitet ball and the standard yield. Figure 3 shows the examples of forming regression dependencies of the standard cereals yield on the soil bonitet point for agroclimatic subzones on the right bank of the Saratov Region defined during the agro-climatic evaluation zoning [13].

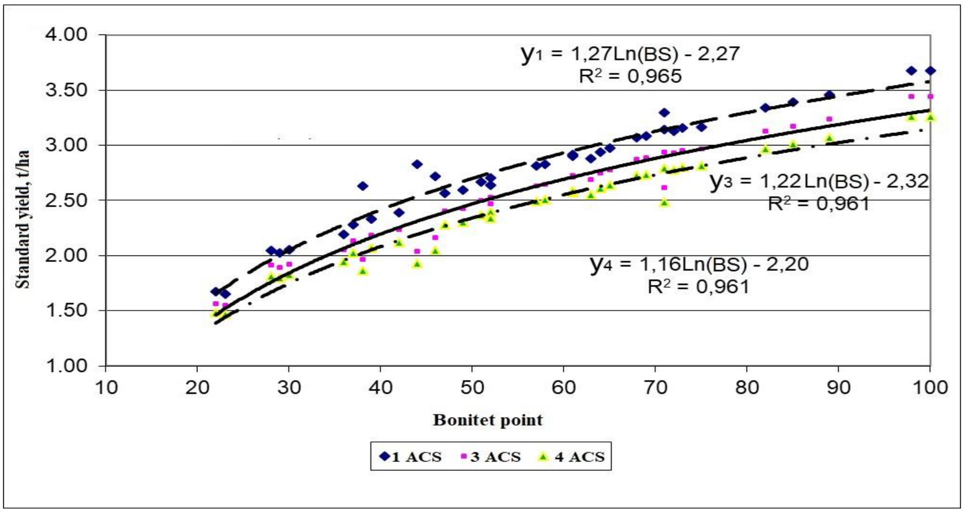

Fig. 3. Dependence of the Standard Yield of Cereals (Y) on the Soil Bonitet Score (BS) for the Agro-Climatic Subzones (ACS) of the Right Bank of the Saratov Region

V. IMPACT ON THE ADEQUACY OF EVALUATING THE USE OF ACTUAL RATHER THAN STANDARD PARAMETERS OF PRODUCTIVITY AND COSTS

Due to the complexity to correctly account all cost-forming factors in the production price, it is peri-odically offered to use actual rather than standard costs when evaluating lands [14]. This approach was implemented by the methodology of the first two rounds of the cadastral evaluation of agricultural land. This approach clearly contradicts the very concept of land rent taking into account the realities of the modern agricultural production, when the old equipment is written-off 1.5 – 1.7 times more often than the new one is bought [15], and the doses of fertilizers are much lower than required for the reproduction of soil fertility.

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In particular, nowadays the uncompensated removal of the mineral nutrition elements and the yield are on average 68.6 kg of the NPK active substance in the Saratov Region, and 130 – 140 kg – for the north-western regions with a high agro-resource potential of land [16]. In 2017 only the cost of mineral fertilizers of the uncompensated removal of mineral nutrition was RUB 3.0 and 5.5 thousand, respectively, which was comparable and often exceeded the amount of accounting profit before tax on the arable land for most areas of the Saratov Region.

The studies showed [17] that the use of actual (accounting data) rather than standard values of productivity and production costs in determining the rental income for a group of cereals caused a relative error that exceeded 100 %. Table 3 shows the absolute values of the error of the evaluation indicators averaged for the Saratov Region and the parameters of the errors' variation in the context of certain administrative regions when using the reported statistical data for the evaluation. When defining the evaluation indicators, the average relative error when using the actual parameters of yield and costs was as follows: the product value – 77.7 %, production costs – 69.9 %, and the net income – 106.7 %. The difference in the level of using the agro-resource potential of the arable land in various districts of the region that varies in the range from 34 to 88 % makes a considerable contribution to the ambiguity of the net income determined by the actual yield makes it possible to determine the standard yield, whose value corresponds to the concept of standard.

Table 3. Average Error of Evaluation Indicators and Parameters of their Variation (RUB/ha)

Indicators	Production value (PV)		Production cost (PC)		Net income (NI)		Absolute error when determining		
	Actual	Standard	Actual	Standard	Actual	Standard	NI	PV	PC
Average	6,046	10,741	4,779	8,121	1,267	2,620	1,353	4,695	3,342
Mean square deviation	1,786	2,884	1,350	1,028	993	1,856	1,514	2,046	1,206
Variation coefficient	29.5	26.8	28.3	12.7	78.4	70.8	111.9	43.6	36.1

VI. CONCLUTION

1. The current regulatory and methodological provisions on accounting soil fertility when monitoring agricultural land and forming the FS EAAL information system do not provide an unambiguous understanding of the primary object for the quantitative measurement of soil fertility parameters.

2. The set of parameters, the method of their defining and spatial presentation on elementary areas during agrochemical surveys do not allow including the information obtained into the system of land certification by the characteristics required for individual and mass land evaluation for the purpose of taxation, land zoning by fertility and agricultural land market regulation, land management by using the principles of ecological-landscape organization of the territory.

3. The implementation of the systematic approach when forming the soil fertility database as a state information resource suggests the unification of indicators in the agro-ecological and economic evaluation of land based on the offered formalization of the concept "standard yield". Out of all models that can be implemented on the basis of information about soil quality characteristics that is available for mass evaluation, only the model based on the interregional evaluation of the territory's agro-resource potential [12]

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