Geoinformation modeling of agricultural land transformation

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Abstract. The article considers the economic and mathematical modeling methods, used to justify the transformation of agricultural land. A study of possibilities of geoinformation modeling methods for assessing the set of conditions that ensure the suitability of land for conversion to particular type of land has been carried out. The structure of geodatabase for conducting geoinformation modeling of agricultural land transformation is presented. Examples of application of geoinformation modeling operations for agricultural land transformation on specific land plots are considered.

Introduction

According to global statistics, agricultural land is being withdrawn from circulation as a result of degradation processes and their transfer to other non-agricultural types of land. It has been established that in countries such as Montenegro and Greece, the reduction in agricultural land area amounted to 19.1% (from 2010 to 2021) and 11.9% (from 1970 to 2021) of the all land area, respectively. Less significant reductions in agricultural land area were observed in Moldova (by 5.9% from 2000 to 2021), Italy (by 4.9% from 1970 to 2021), Australia (by 4.3% from 1970 to 2021), and the Republic of Belarus (by 3.4% from 2000 to 2021) [1]. In the Russian Federation the reduction in agricultural land area is less critical. Thus, according to Russian registry from 1990 to 2022 the total area of agricultural land in the Russian Federation (RF) decreased by 0.03% of the all land area [3, 4]. At the same time, one of the significant problems in the system of rational land use in the RF is the presence of unused agricultural land. The Ministry of Agriculture notes that the area of unused agricultural land in the Russian Federation is estimated at almost 44 million hectares, of which 20 million hectares are arable land [2]. The reasons for the non-use of agricultural land in Russia include: complex reasons, related to reform of land relations and weakening role of state in land management; economic reasons, expressed in unsatisfactory financial and economic situation of agricultural producers, leading to absence of necessary measures to maintain soil fertility; organizational and economic reasons, related primarily to absence of complex land management projects [5].

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One of land management measures for involving unused agricultural land in circulation is their transformation. Transformation allows to come to intensification of land use, thereby increasing the efficiency of agricultural production. At the same time, as Academician Volkov S.N. notes, during transformation, territorial requirements for the location of agricultural lands must be observed, and "conditions for improving the water-air and thermal regime of soils, increasing their fertility, increasing crop yields, and improving the conditions for field work mechanization" must be created [6]. However, in conditions of uncertainty, created, among other things, by modern market relations, it is impossible to carry out effective land transformation without preliminary modeling of its results.

Materials and methods

The object of this study is land plots in the territory of the Republic of Crimea, unused or inefficiently used in agricultural production (Figure 1).

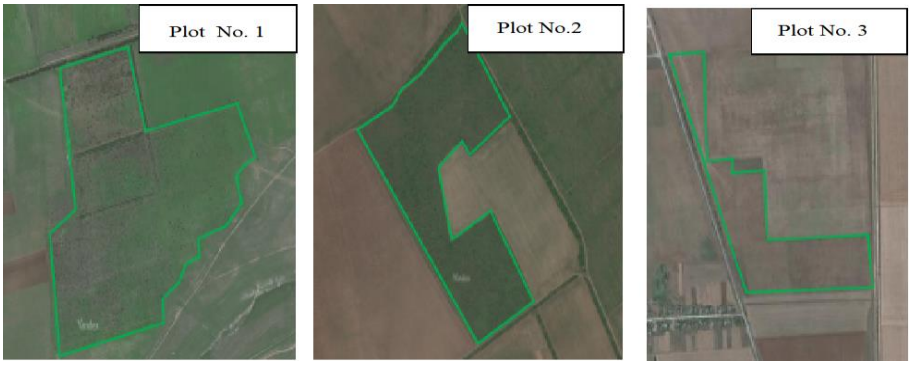


Fig. 1. Land plots in Chernomorsky (No. 1 and No. 2) and Saksky (No. 3) districts with unproductive sparse perennial plantings, 2024 (fragments of satellite images from the Scanex Engineering and Technology Center [7])

During land management of the studied land plots, at least two options for measures are often considered to solve the identified problems: 1) reconstruction may be proposed to increase the efficiency of perennial plantings; 2) intensification of agricultural production on such plots can be achieved through the land transformation - uprooting unproductive perennial plantings and land plowing. In this case, the choice of one or another measure must be economically and ecologically justified.

The literature widely describes economic and mathematical methods for finding the optimal solution to land management problems, which are used to model the transformation of land. Volkov S. N. points out that "Economic and mathematical model of land transformation is formulated as follows. The unknowns x_{ij} are the area of the *i*-th land transformed into the *j*-th, as well as areas of meliorative objects that include various lands" [8]. In this case, various restrictions are imposed on the unknowns, such as:

- availability of lands, suitable for transformation;
- costs of money for transformation;
- labor resources;
- availability of machines and mechanisms;
- need for fertilizers;
- limit of irrigation water;
- capital investments allocated for transformation;
- efficiency of capital investments.

«The objective function of this problem is as follows (1):

$$Z = \sum_{(i,j)} c_{ij} x_{ij} \rightarrow max \quad (1)$$

As c_{ij}, one can use the net income received from the transformed areas q_j or the increase in net income q_{ij}.» [8].

However, considering the current trends in digitalization, there is a need to study the capabilities of geoinformation modeling methods for comprehensive and prompt assessment of set of conditions justifying the lands suitability for conversion to one or another type of land. Among the above-mentioned limitations for land transformation, the use of geoinformation modeling can be justified primarily for determining the availability of lands suitable for transformation.

The following cartographic materials were used as initial data for conducting geoinformation modeling of agricultural land transformation:

1) geodata for the study area, freely available on open geoportals in the Internet;

2) soil map of the Republic of Crimea, compiled in 1967 [9], which, according to soil scientists, is the most informative soil map of Crimea [10]. This map provides information not only on soil varieties, but also soil characteristics by degree of erosion, salinity level, and granulometric composition;

3) map of surface water bodies of the Republic of Crimea [11] and cartographic model of spatial distribution of moisture supply on the territory of the Crimean Peninsula [12];

4) other cartographic materials, reflecting the characteristics of the territory according to indicators, justifying land transformation.

Results

The input parameters for geoinformation model are indicators and criteria for assessing validity of transforming agricultural land, specified in Table 1, which, in turn, can be supplemented depending on the location conditions of transformed lands.

Table 1. Indicators and models for assessing land management decisions on land transformation

No.	Indicators justifying land transformation	Models for solving land management tasks in the course of justifying land transformation
1	2	3
1	Location of land plot (array) in relation to economic centers (under conditions of modern land use, settlements where agricultural markets or processing plants are located can be considered as economic center)	*Condition:* total transportation costs should be minimal. *Economic and mathematical modeling:* distribution (transport) model is used, the objective function of which looks like this: $Z = \sum_{(i,j)} C_{ij} x_{ij} \rightarrow min$, where C_{ij} is the cost of transporting a unit of resource from the *i*-th source to the *j*-th consumer [8]. *Geoinformation modeling:* an analysis of network objects is performed, as a result of which their location within given distance and time and cost of moving along them from the source are assessed [13].
2	Moisture supply of land plot (array) and availability of water supply sources for irrigation network creation	*Condition:* maximum net income per unit of reduced costs for a specific indicator. *Economic and mathematical modeling:* linear optimization task is used, the objective function of which looks like this: $Z = F(x) = \sum_{j=1}^{n} c_j x_j \rightarrow max$. In this case, c_j is the profit, received per unit of

Continuation of the Table 1

1	2	3
2		dimension, adopted for the object, designated x_j, calculated using the following formula: $c_j = \frac{P_j}{S_j + EK_j}$, where P_j is the net income for the j-th object, S_j is the cost of production for the j-th variable, E is the standard coefficient of capital investment efficiency; K_j is the specific capital investment per unit of dimension, adopted for the variable x_j [8]. *Geoinformation modeling:* to classify a territory by moisture availability an analysis of the distribution of numerical indicators is used, namely, climatic factors characterizing the moisture availability of the territory [13, 12]; to determine the presence and types of water supply sources an analysis of their distribution in the study territory is performed with grouping by categories [13].
3	Soil quality	*Condition:* planned yield on the soil variety is taken into account. *Economic and mathematical modeling:* yield planning methods are used. For example, $Y_p = C_p \times B_p$, where Y_p is the planned yield on the soil variety, centners per 1 ha; C_p is the price of a point (yield per 1 point); B_p is the soil bonitation point (or economic assessment of lands) for a given crop. *Geoinformation modeling:* ranking soils by suitability for cultivating different types of agricultural crops (the rank is assigned based on an attribute or combination of attributes of the object) [13].
4	Erosion hazard	*Condition:* the placement of agricultural crops by categories of erosion-hazardous lands should be carried out in such a way that the potential soil flushing during crop cultivation is minimal [8]. *Economic and mathematical modeling:* distribution method of linear programming is used. The structural form of the model has the form: $Z = \sum_{j=1}^{n} \sum_{i=1}^{m} c_{ij} x_{ij} \rightarrow min$, where n is the number of agricultural crop types; m is the number of categories of erosion-hazardous lands; j is the index of agricultural crop (j= *1, 2, …, n*); i is the index of category of erosion-hazardous lands (i= *1, 2, …, n*); x_{ij} is the area of the j-th agricultural crop on the i-th category of erosion-hazardous lands; c_{ij} is the intensity of soil loss under crops of the j-th agricultural crop on the i-th category of erosion-hazardous lands [8]. *Geoinformation modeling:* analysis of model tabular data by categories of erosion hazard, intensity of soil flushing, erosion hazard coefficients of agricultural crops [8, 13].
5	Land plot configuration	*Condition:* the longer the run length (main indicator, characterizing the field configuration) on fields of regular shape, the lower the costs of idle turns and arrivals of agricultural machinery, and labor productivity during field work is higher. *Economic and mathematical modeling:* the relationship between the costs of idle turns and machinery arrivals and the run length (x) is expressed by the hyperbola equation: $y = a_0 + \frac{a_1}{x}$. Tightness of the curvilinear connection can be determined by calculating the correlation ratio: $R = \sqrt{\frac{\sigma^2 - \sigma_p^2}{\sigma^2}}$, the statistical reliability of which for small samples is determined by the formula: $\sigma_R = \frac{1-R^2}{\sqrt{n-2}}$ [8]. *Geoinformation modeling:* analysis of model tabular data by the length of the site working run values.

It should be noted that the quality of geoinformation modeling results is directly dependent on completeness and relevance of geodatabase, the structure of which we propose in Figure 2.

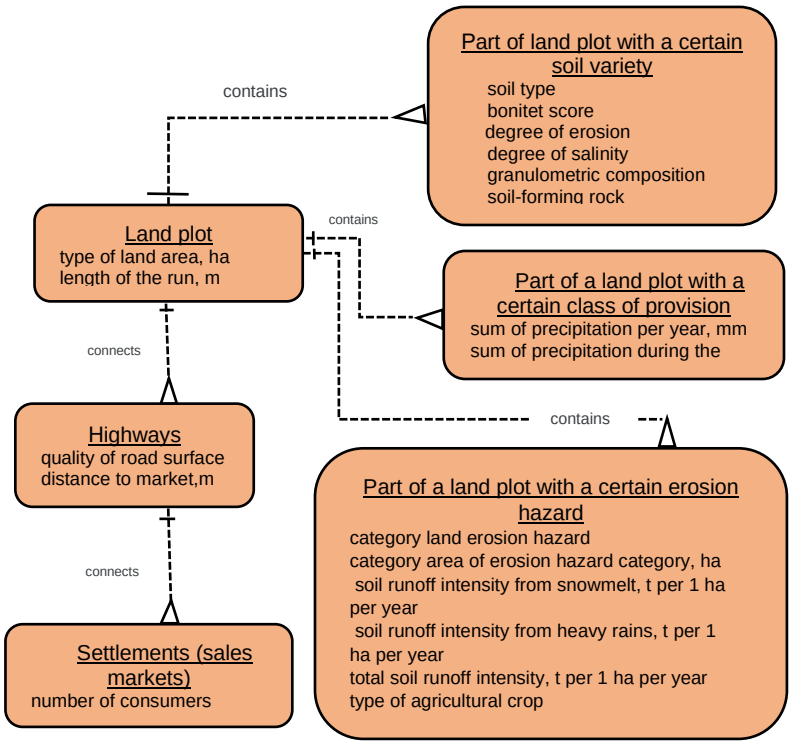
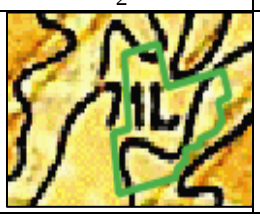
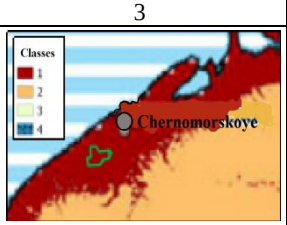


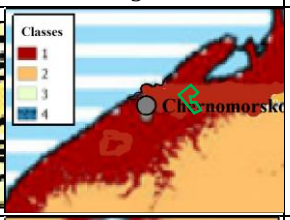
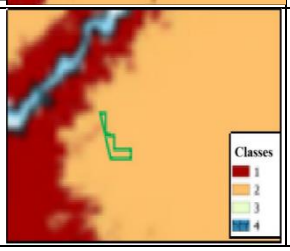
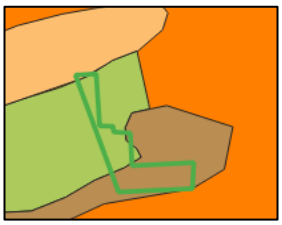
Fig. 2. Structure of the geoinformation database for land transformation modeling in the form of an ER diagram in Martin notation, compiled using Visual Paradigm Online

The organization of data for the purposes of geoinformation modeling of agricultural land transformation is performed layer by layer, which allows for overlay operations with polygonal objects and assessing the suitability of land plot for transformation, based on some indicators (Table 2).

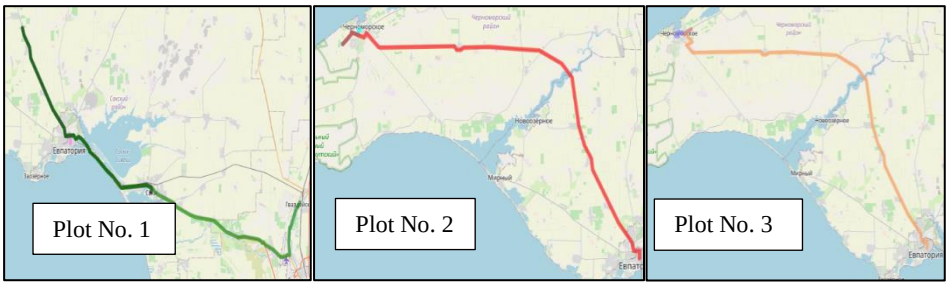
Table 2. Geoinformation modeling using overlay operations with polygonal layers

Land plot number	Geospatial information layers for overlay operation		Result of the overlay operation (an overlay of the "trace" type is used, when polygons from one layer are superimposed on polygons of the second layer)
	Soil map [9]	Map of spatial distribution of moisture supply [12]	
1	2	3	4
Plot No.1			

Continuation of the Table 2

1	2	3	4
Plot No.2			
Plot No.3			

During the analysis of location of land plots in relation to economic centers, layers of linear networks were prepared, tied to highways connecting the research objects with agricultural markets in populated areas - centers of rural, urban settlements and administrative districts of the Republic of Crimea (Figure 3).



Distance from plots to agricultural markets (km) in different settlements					
Chernomorskoye urban-type settlement	4,76	Chernomorskoye urban-type settlement	4,11	Evpatoria city	21,6
Evpatoria city	77,6	Evpatoria city	75,5	Saki city	42,9
				Gvardeyskoye urban-type settlement	82,5

Fig. 3. Routes built along highways and distances to agricultural markets in different settlements

4 Discustion

As a result of the conducted study, the following characteristics of land plots were obtained, necessary for justifying the transformation of agricultural land:

1) land plots No. 1 and No. 2 are located close to the agricultural market in the center of the administrative district (urban settlement of Chernomorskoye). However, the number of consumers in the seaside village can fluctuate significantly depending on the resort season, so it is necessary to consider the possibility of transporting products to the city of Yevpatoriya. At the same time, the distance between the plots and the point of sale or processing of products increases, therefore, transportation costs also increase. Land plot

No. 3 is more advantageously located in relation to sales markets, since it has a shorter distance to larger and seasonally independent markets;

2) the soil conditions of plots No. 1, No. 2, No. 3 are similar and are represented by the following soil types: 71L – southern low-humus mycelial-high-carbonate chernozems on loess and loess-like rocks (No. 1, 2, 3); 79ek – predominantly carbonate rubble and stony chernozems on the eluvium of dense carbonate and carbonated rocks (No. 1, 2, 3). These soil types are unsuitable for many fruit crops that are sensitive to high carbonate content. Part of land plot No. 3 is represented by meadow-chernozem carbonate soils on loess and loess-like rocks (96L), which may be suitable for growing crops less sensitive to the carbonate content of soils; however, this soil variety is characterized by a close occurrence of groundwater, which is unfavorable factor for planting orchards and vineyards;

3) based on moisture availability factors, it was established that plots No. 1 and No. 2 are located within the boundaries of class 1 – very arid zone of the Crimean Peninsula [12]. More favorable moisture availability conditions are found on plot No. 3 (class 2 – arid zone [12]). When assessing the location of water supply sources, it was revealed that plot No. 3 is located at a close distance to the Saki branch of the North Crimean Canal;

4) based on the degree of soil flushing: soils on plot No. 1 are slightly and moderately flushed; on plot No. 2 – slightly flushed; on plot No. 3 – moderately flushed [9];

5) based on configuration conditions, it should be noted that on plots No. 1 and No. 2 it is possible to organize fields and working areas with run length of 500 m; On the part of plot No. 3, suitable for transformation into arable land, the length of the working run can be up to 1000 m. In general, the land plots under consideration can be divided into fields and working plots of regular geometric shape. With regard to land plot No. 2, the use of geoinformation modeling made it possible to determine that transformation into arable land will lead to the elimination of wedging and broken boundaries of adjacent arable land plots. Taking into account the listed conditions, land plots No. 1 and No. 2, shown in Figure 1, are more suitable for transformation into arable land. The following solutions should be considered for land plot No. 3: on the part of the plot with soils more suitable for growing grapes - partial or complete renewal of vineyards, and on the part with less favorable conditions for this crop - transformation into arable land is desirable.

5 Conclusion

As a result of the study, it was established that geoinformation modeling allows for quick and visual assessment of land suitability for transformation. However, to obtain high-quality results in the geoinformation model, it is necessary to rely on traditional methods of economic and mathematical modeling for the indicators of transformation justification. At the same time, important factor, determining the quality of the results of geoinformation modeling, is up-to-date and complete database.

Geoinformation modeling of land transformation, due to speed of its implementation, acts primarily as preliminary express assessment of effectiveness of land management decisions on land transformation, which may be in demand when considering investment projects for the development of unused land plots, business plans for perennial plantings creation, etc.

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