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Land Transformation and its Impact on Soil Quality, Bonitation Scores and Cadastral Value Through Economic-Mathematical Modeling

Inga Beglaryan[1], Anush Harutyunyan[2]

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ABSTRACT

Background: Land transformation significantly impacts the physical, legal, and economic characteristics of agricultural resources. This study explores the role of economic-mathematical modeling in optimizing land use efficiency through land cover transformation in the Aghavnadzor community of Vayots Dzor, Armenia.

Methods: The research focused on a 7.5-hectare area (1450-1600m altitude) from 2021 to 2024. Characterized by a dry subtropical climate and humus-poor gray soils, the site served as a controlled environment to minimize climatic variability. The methodology integrated soil chemical analysis, bonitation (soil quality) assessment, and cadastral valuation within an economic-mathematical framework to evaluate the transition from low-value to high-value agricultural land types.

Result: Findings reveal that strategic land transformation substantially improves soil chemical composition, including organic matter and essential nutrients. Quantitative analysis showed a 20-30% increase in bonitation scores, leading to a proportional rise in cadastral value. The mathematical model successfully identified resource constraints and "bottlenecks," providing a robust framework for sustainable land management. Notably, the transformation yielded a projected net community income of $17,000 USD, demonstrating significant local economic benefits. This integrated approach offers a scientifically grounded decision-making tool for land use planning. By linking soil properties with modern agricultural practices and economic outcomes, the study provides a scalable model for enhancing land productivity and rural financial stability in similar geographic regions.

Key words: Land transformation, Soil quality, Bonitation score, Cadastral value, Economic-mathematical modeling, Land use optimization.

INTRODUCTION

In the modern world, the efficient use of land resources plays a crucial role in agriculture, economics and environmental sustainability. Land is not only a fundamental means of agricultural production but also an essential spatial, ecological and economic resource. Changes in land use-whether caused by urbanization, industrial expansion, agricultural development, or natural processes-significantly alter the physical, chemical and legal characteristics of land (Zhang *et al*., 2023; Bykowa and Banikevich, 2025).

These transformations affect soil fertility, land-use suitability and ecological value, as well as land assessment indicators such as bonitation scores and cadastral value, which are vital for taxation, planning and investment decision-making.

In contemporary agriculture, the application of scientific and technological approaches, particularly mathematical modeling, has become increasingly important (Tegenie *et al*., 2022; Smith *et al*., 2016; FAO, 2017). Economic-mathematical modeling serves as an effective tool for analyzing and optimizing land use efficiency, evaluating resource limitations and developing strategies for sustainable development (Walangitan *et al.,* 2012; Xin *et al.,* 2020; Taratula *et al.,* 2019; Ma and Wen, 2021). Through such modeling, it is possible to identify the key limiting factors-often referred to as "bottlenecks"-that restrict efficiency and to design strategies for improving land productivity and economic performance.

[1]Hrant Petrosyan Scientific Center of Soil Science, Agrochemistry and Melioration Branch of Armenian National Agrarian University (ANAU) Foundation, 24 Isakov Ave., Yerevan 0004, RA.
[2]Institute of Economics after M. Kotanyan, The National Academy of Sciences of Armenia.

Corresponding Author: Inga Beglaryan, Hrant Petrosyan Scientific Center of Soil Science, Agrochemistry and Melioration Branch of Armenian National Agrarian University (ANAU) Foundation, 24 Isakov Ave., Yerevan 0004, RA.
Email: inga.beglaryan2@gmail.com
ORCID: https://orcid.org/0000-0002-8443-3254, 0009-0009-3092-5331

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The main objective of this study is to assess the impact of land cover transformation on soil qualitative properties, bonitation scores and cadastral values through the application of economic-mathematical modeling. This integrated approach enables the evaluation of how converting low-value land types into more productive ones can enhance soil fertility, improve agricultural potential and

increase the economic and cadastral value of land (Volungevicius and Skorupskas, 2011; Zhang *et al.,* 2023).

The study combines soil chemical analysis, bonitation assessment and cadastral valuation to develop a comprehensive understanding of how land transformation affects both the qualitative and economic aspects of agricultural resources. The results aim to provide a scientific and practical basis for sustainable land management policies, inform agricultural investment decisions and support the optimization of spatial and economic planning in similar geographic and climatic regions (Fig 1).

MATERIALS AND METHODS

Land transformation, particularly the conversion of low-value agricultural lands into higher-value types, is of special relevance in many regions of Armenia, where natural and climatic conditions are diverse and often present challenges for intensive agricultural development. For this study, the Aghavnadzor community in the Vayots Dzor region was selected as the research area (Fig 2). The administrative area of the community is 4,682 hectares: 466 hectares of arable land, 1,071 hectares of pasture and 379.4 hectares of orchards (Armenian Ministry of Agriculture, 2022).

The altitude is 1,450-1,600 meters above sea level and in the central part it is 1,530 meters high, characterized by a subtropical dry climate and humus-poor gray soils. The Aghavnadzor plateau has an ancient volcanic structure and is cut by numerous small rivers and ravines. The climate is characterized by a subtropical dry climate, with dry and hot summers and wet, moderately cold winters. The amount

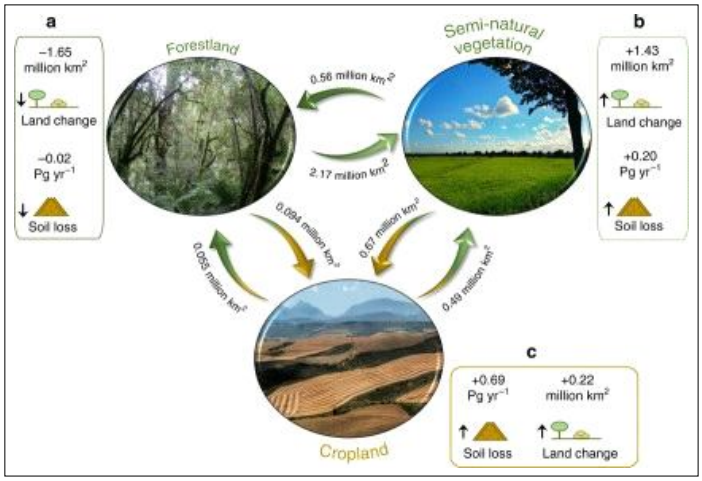


Fig 1: Flow diagram of land use changes and their effects on the soil.

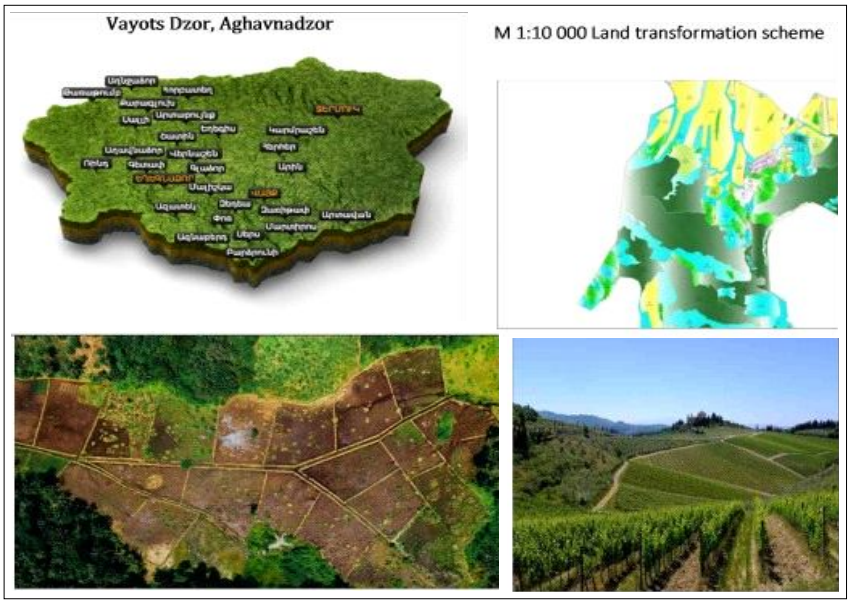


Fig 2: Optimal scheme for land transformation.

of precipitation varies from 350-400 mm. Autumn is long and warm, under which conditions fruits ripen, especially various types of grapes. The main branch of the village economy is agriculture, mainly engaged in fruit growing and viticulture.

The choice of this area ensured stable altitude and climatic conditions, minimizing external variability and allowing for more accurate modeling and assessment of land transformation impacts.

One of the main challenges in land management is developing efficient schemes for the transformation of agricultural land types, which allows for a transition from the current land use structure to a more effective land use system (Volkov, 2001; Walangitan *et al*., 2012; Dash *et al*., 2025; Hurni, 2000). To develop the economic-mathematical model, let represent the area of the i-th plot of land that is transformed into -ith plot, considering different types of land. The system of constraints will be as follows (Taratula *et al.,* 2019; Dobrovolsky and Kireeva, 2019, Klimenko *et al.,* 2024).

A constraint based on the availability of land suitable for transformation:

$$\sum_j x_{ij} \le P_i \; i \in M_1$$

A constraint based on the financial expenditure required for the transformation‰

$$\sum_j a_{ij} x_{ij} \le A_i \; i \in M_2$$

A constraint based on the use of machinery and mechanisms (capacity of both in-house and contracted construction organizations)‰

$$\sum_j l_{ij} x_{ij} \le L_i \quad i \in M_4$$

A constraint based on the use of fertilizers.

$$\sum_j w_{ij} x_{ij} \le W_i \; i \in M_5$$

A constraint based on the efficient use of labor resources:

$$\sum_j t_{ij} x_{ij} \le T_i \; i \in M_3$$

A constraint based kn the use of irrigation water (community irrigation):

$$\sum_j h_{ij} x_{ij} \le H_i \; i \in M_7$$

A constraint based on the capital investment costs for transformation:

$$\sum_j d_{ij} x_{ij} \le D_i \; i \in M_8$$

A constraint based on the use of treatment materials:

$$\sum_j k_{ij} x_{ij} \le K_i \quad i \in M_6$$

A constraint based on the effectiveness of capital investments.

The payback period for capital investments (Tt) is determined by the following formula:

$$T^t = \frac{\sum_{ij} d_{ij} x_{ij}}{\sum_{ij} q_{ij} x_{ij}}$$

The non-negativity condition for the variables can be expressed as the objective function takes the following form:

$$Z = \sum_j c_{ij} x_{ij} \rightarrow \max$$

The net income determined using the following formula‰

$$q_i = B_i - C_j,\; q_i = B_j - C_i.$$

RESULTS AND DISCUSSION

The transformation of agricultural land should be carried out based on the condition that the economic efficiency of the economy strives for its maximum potential (Table 1,2).

The expanded numerical matrix of the problem is presented in Table 3, while the results of the optimization solution are presented in Table 4. The problem is a linear programming problem, which was solved using an Excel program's Solver subroutine.

Thus, in the Aghavnadzor community of Vayots Dzor, Armenia, it is necessary to transform 2.5 hectares were

Table 1: Key variables in land transformation.

Land areas according to the project	Arable land, hectares	Fruit orchard, hectares	Vineyard, hectares	Mulberry Orchard	Grasss land	Land suitable for transformation
Arable land	-	-	X_1	-	-	2
Grassland	X_2	-	-	X_3	-	2.5
Pasture	-	X_4	-	-	-	2.6
Other land plots	-	-	-	-	X_5	2.8

Table 2: Baseline data for the problem.

Land areas for land reclamation in the year	Intended use	Variables	Expenditures on the transformation: Capital investments per hectare, in currency (AMD)	Labor costs per hectare, man-days	Machinery costs per hectare, machine-days	Mineral fertilizer usage hectare, centner	Cost of treatment per hectare, currency	Yield, quintals per hectare: Before transformation materials	After transformation	Unit production value, currency (AMD): Before transformation	After transformation	Production costs per hectare, currency (AMD): Before transformation	After transformation
Arable land	Vineyard	X_1	1200000	35	5.0	2.5	80000	250	230	7000	15000	1520000	1850000
Grassland	Arable land	X_2	550000	135.5	7.5	3.6	180000	30	280	4500	8500	50000	1200000
	Mulberry orchard	X_3	400000	15.5	4.2	3.5	80000	30	90	4500	25000	50000	180000
Pasture	Fruit orchard	X_4	470000	15.8	3.0	2.7	98000	3	150	5000	12000	0	1052000
Other land plots	Grassland	X_5	350000	8.0	6.5	1.8	0	0	90	0	6500	0	120000

Table 3: The expanded numerical matrix of the problem.

	Variables: Arabel land (x1)	Fruit orchard (x2)	Vineyard (x3)	Mulberry orchard (x4)	Grasslad (x5)	Type of constraints	Right-hand side of the constraints
Values of the variable	0	0	0	0	0	-	-
Arabel land,	0	1	0	1	0	≤	2
Grassland	1	0	1	0	0	≤	2,5
Pasture	0	0	0	1	1	≤	2,2
Other land plots	0	0	0	0	1	≤	2,5
Capital investments, currency (AMD)	470000	400000	550000	350000	1000000	≤	3500000
Labor costs, person-days	16	14	140	8,5	33	≤	280
Machine costs, machine-day	3,5	4,5	6,8	5,5	4,8	≤	50
Mineral fertilizer usage, centners	3	3,4	4	2,0	2,7	≤	18
Cost of treatment materials, currency (AMD)	95000	80000	185000	0	85000	≤	450000
Capital investment efficiency, currency (AMD)	-471100	-1239500	-1056500	-265500	-20000	≤	0
Net income, currency	640000	1400000	1230000	432500	140000	→	Max

Table 4: The results of the problems computational solution.

Variables	Arable land (x1)	Fruit orchard (x2)	Vineyard (x3)	Mulberry orchard (x4)	Grassland (x5)	Amount of unused resources	Type of constraints	The right-hand side of the constraints
Values of the variable	0,0	2,5	1,2	2,6	0,0	-	-	-
Arabel land	1	1	0	0	0	2,5	≤	2
Grassland	0	0	1	0	0	1,189189189	≤	2,5
Pasture	0	0	0	1	0	2,6	≤	2,2
Other land plots	0	0	0	0	1	1,189189189	≤	2,5
Capital investments, currency (AMD)	470000	400000	550000	350000	1000000	2564054,054	≤	3500000
Labor costs, person-days	16	14	140	8,5	33	223,5864865	≤	280
Machine costs, machine-day	3,5	4,5	6,8	5,5	4,8	33,63648649	≤	50
Mineral fertilizer usage, centners	3	3,4	4	2,0	2,7	17,86216216	≤	18
Cost of treatment materials, currency(AMD)	95000	80000	185000	0	85000	420000	≤	450000
Capital investment efficiency, currency (AMD)	-471100	-1239500	-1056500	-265500	-20000	-5045428,378	≤	0
Net income, currency (AMD)	640000	1400000	1230000	432500	140000	6087202,703	→	Max

converted into a mulberry orchard, 1.2 hectares of grassland were converted into arable land, 2.6 hectares of pasture were transformed into grassland and 1.2 hectares of other land types were converted into arable land (Table 4). The calculations have been made in Armenian drams and the final result is presented in dollars. As a result of the conversion, the Aghavnadzor community will receive an income equivalent to 17.000 dollars in drams; in a similar solution to the problem, the proposed method is applicable to any community, providing the opportunity to transition from the current land use structure to a more efficient land management system.

The results of soil transformation confirm the theoretical expectations of how soil quality improvement and optimal land-use modeling can enhance agricultural and economic benefits (Gasparyan *et al*., 2025; Beglaryan *et al*., 2025; Zhang *et al*., 2023).

Improvement of soil chemical composition

After transformation, soil organic matter increased from 1.2% to 2.1% (+75%) and the main nutrients-nitrates, phosphorus and potassium-rose by 57%, 44% and 33%, respectively. These improvements directly influenced soil fertility and increased the bonitation score from 45 to 58, demonstrating that well-planned land transformation strategies can effectively restore or improve low- and medium-value soils (Table 5).

Increase in bonitation and cadastral value

The bonitation score rose by 28.9% and the cadastral value increased by 36%, highlighting the close link between soil quality and economic valuation (Bykowa and Banikevich, 2025; Volkov, 2001). The increase in cadastral value indicates that the land has become not only more fertile but also economically more valuable, which is important for community investment and tax planning (Table 6).

Efficiency of the economic-mathematical model

The model identified key resource constraints (bottlenecks) and suggested optimal adjustments. The calculated net income, Zmax = 17,000 USD, confirms that the model accurately predicts real economic benefits and can serve as a basis for community land management strategies.

Comparison of pre- and post-transformation conditions

Analysis shows that all key indicators-from soil chemical composition to financial profit-improved significantly, proving that transforming low-value lands into high-value lands has strong agricultural and socio-economic potential.

Practical and applicable recommendations

Modern mathematical models can be used to plan efficient and sustainable land-use strategies for different land types. Soil restoration and improvement efforts should be combined with economic modeling to maximize income. The model is extendable to other similar regions with comparable climate and soil conditions.

Table 5: Changes in soil quality and economic indicators before and after transformation.

Indicator	Before transformation	After transformation	Change (%)
Organic matter (%)	1.2	2.1	+75.0
Nitrate content (mg/kg)	8.5	13.4	+57.6
Phosphorus (mg/kg)	14.2	20.5	+44.4
Potassium (mg/kg)	180	240	+33.3
Bonitation score	45	58	+28.9
Cadastral value (USD/ha)	2,500	3,400	+36.0
Agricultural income (USD/ha)	1,800	2,600	+44.4
Total net income (USD, 7.5 ha)	13,500	17,000 (Zmax)	+45.7

Table 6: Bonitation scores and cadastral values.

Land type	Initial Bonitation Score	Transformed Bonitation Score	Score Change (%)	Initial Cadastral Value (USD/ha)	Transformed Cadastral Value (USD/ha)	Value Change (%)	Net Income (USD/ha)
Low-value land	45	58	+28.9	2,500	3,400	+36	2,600
Medium-value land	52	63	+21.2	3,200	4,050	+26.6	3,100
High-value land	65	70	+7.7	4,500	5,000	+11.1	4,300

CONCLUSION

Land transformation combined with economic-mathematical modeling demonstrated that low-value agricultural lands can be efficiently converted into high-value lands. Transformation resulted in improved soil chemical composition, a 20-30% increase in bonitation score and a significant rise in cadastral value.

The model effectively identified key constraints and suggested optimal land-use strategies, enhancing productivity, economic efficiency and community financial well-being (net income Zmax = 17,000 USD).

The results highlight the strong connection between soil properties, modern agricultural practices and mathematical modeling, showing that integrated approaches can ensure sustainable and efficient land management in the studied area and other regions with similar climatic and soil conditions.

Conflict of interest

The authors declare no conflict of interest.

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