Soil and Landscape Changes in Ancient Agricultural Areas (Exemplified by Antique Olbia)

F. N. Lisetskii and M. E. Rodionova

Belgorod State University, Belgorod, Russia
e-mail: Liset@bsu.edu.ru
e-mail: zamuraeva@bsu.edu.ru

Abstract—We report results from studying the landscapes of the rural surroundings of antique Olbia and substantiate the indicators of long-term agrogenic transformation of the physicochemical properties of dry-steppe soils which have experienced long-lasting agricultural pressures.

Keywords: agrogenically transformed soils, antique land use, post-antique landscapes, agrogenic indicators.

INTRODUCTION

Soils in geosystems over a definite period of their evolution reflect and selectively record (memorize) not only the impact of natural pedogenic factors but also, in many cases, the nature management practices differing in duration and intensity. While living matter, notably vegetation, has the role of the main driving force in the evolution of biogeocenoses, the soil is the component of biogeocenoses which embeds evolutionary changes [1]. On relatively young soils, the characteristics of the soil-forming process, and the composition and production of phytomass are governed by the properties of substratum and climate, i.e. by the abiotic invariant structure [2], whereas in the case of polygenetic anthropogenically transformed soils, their properties are determined by the contemporary development of soils and vegetation [3].

An extensive body of knowledge of the agrogenic transformation of soils at the current stage of development has been accumulated to date. An important point is that, given a significant duration of agriculture, the soils can "memorize" some evidence for changes in the properties corresponding to the evolution dimension. Analysis of long-term impacts of agriculture on soils was made in publications devoted to the Non-Black earth Zone of Russia [4, 5], the southern part of Ukraine [6], the Black Sea region [7], South America [8, 9], etc. In the case of studying the agrogenic transformation of soils, however, the spatial diversity of their modifications is, usually, poorly correlated with the morphological structure of heterochronous agrolandscape systems, i.e. the landscape context must be invoked when analyzing the evolution of soils and soil cover.

The objective of this study is to determine the indicators of long-lasting agrogenic transformation of the physicochemical properties of dry-steppe soils, based on using a rare (in duration) history of their agricultural development in landscapes of the rural neighborhood of antique Olbia (the territory of the contemporary Mykolaiv oblast of Ukraine).

OBJECTS

In Antique Times, because of the Greek colonization, trade points and cities emerged on the northern coast of the Black Sea (from the Danube to the Don), including the two shores of the Southern Bug Estuary. The study area is situated in the Lower-Bug region (between the villages of Parutino and Dneprovskoe), to the south of Olbia, the center of an ancient Greek state formation of the Polis type. Over the course of a millennium (6th century B. C. – 4th century A. C.) this territory was experiencing anthropogenic impacts of a different intensity which were caused primarily by the nearest (to the city) rural neighborhood (Chora).

Topography of the southern part of the Black Sea Lowland is represented by a flat loessal plain with elevations of 40–45 m which, in the near-liman and maritime zones, changes to abrasion benches. The territory is situated to the south of the contemporary vertical movements of the Earth`s crust, i.e. is experiencing subsidence as much as –1 mm/year. The thickness of clays of the Pliocene red-color and loessal anthropogenic formation occurring above the Pontic limestones reaches 20 m, on the average, but further to the south it increases to 40–50 m.

The main part of the territory sows a weak horizontal dissection by the relict valley-draw network (0.3–0.4 km/km^2); however, gullies are of widespread occurrence in the coastal zones (up to 1–2 km). Thus, the right shore of the Bug Estuary is densely dissected by gullies 25–150 m in length. The gullies have vertical slopes, the tops are 50 m in width, and the depth of some of the gullies reaches 30 m [10]. As was shown in [11], a significant density of the gully-draw network in the coastal zone of the Bug Estuary to the south of Olbia (20 km^2), reaching 1.54 km/km^2, is largely due to the long-lasting functioning of agrolandscapes on catchments of erosional forms.

The climate of the territory is characterized by a high degree of heat availability: with the mean annual temperature of 9.9ºC, the sum of temperatures above 10º is 3380º. The duration of the frost-free period is 209 days; the annual precipitation amount is 330 mm, and the humidification coefficient (the precipitation-to-evaporation ratio) is 0.4.

The study area forms part of the geobotanical region of fescue/feather-grass steppes on dark-chestnut solonetzic soils.

METHODS

A large-scale study into spatiotemporal agrolandscape systems was carried out for the "Olbia" key area; it was selected as a representative study area for historical-landscape investigations. With this end in view, using a unified cartographic base and the ArcGIS 9.3 tools, we integrated the different-time topographic, land-use and soil maps, the bathymetric map of the Bug Estuary, aerial photographs from the year 1974, and space images from Google Earth and TerraLook (from the Quick Bird–2 satellite: summer 2003; resolution 3m; from the ASTER satellite: summer 2001, 2002, 2008 and 2010; resolution 15 m) as well as results of field landscape survey. For representing the complicated historical-geographical situation on the study territory, we developed a matrix-type legend reflecting the actual landscape situation and anthropogenic transformations which we were able to ascertain for the entire period of economic development of the territory. The agrogenetic effects were assessed by using the agrophysical, agrochemical and geochemical indicators of the state of soils. A total of 8 soil samples (S1–S7, …, S9) and parent rock samples (Pr8) were collected.

The results from analyzing the aggregate state and water stability according to Savinov [12] (threefold replication), water stability (fivefold replication), and the content of coprolites were used to calculate the diameter of water-stable aggregates, the biogenicity (the weighted-mean (in mass) proportion of coprolites in structural separates, %), and water stability of aggregates (W) according to Andrianov [12].

The agrochemical group of indicators included the content of humus (according to Tyurin) and of labile organic matter (according to Egorov), CO_2 of carbonates, total nitrogen, labile phosphorus and potassium (according to Chirikov), pH of aqueous and salt extracts, and group analysis of humus (according to Ponomareva and Plotnikova).

Geochemical characteristics are based on the aggregate composition of soils (TiO_2, V, Cr, MnO, Fe_2O_3 ,Co, Ni, Cu, Zn, As, Sr, Pb, CaO, Al_2O_3, SiO_2, P_2O_5, K2O, MgO, Rb, and Na) which was quantified with the X-ray fluorescence analyzer "Spectroscan MAX-GV". The resulting data were used in calculating the eluviations coefficients (K_E), Shaw's modified coefficient of accumulation of the microelements (R), and the indicator $SiO_2/10R_2O_3$.

The formula for calculating the eluviations coefficient involved the basic oxides: $K_E = (SiO_2/(MnO + CaO + K_2O + MgO + Na_2O))$ [13].

A modification of the coefficient as suggested by D.M. Shaw involves calculating its final value as the geometrical mean, i.e. the root to power 7 from the product of the ratios of the content of each microelement (Zn, Cu, Ti, Ni, Cr, and V) in the soil ad parent rock.

A grouping of the soils of the agrogenic series according to the coefficient of accumulation of the element (the ratio of its content in the soil to the parent rock) was carried out with the aid of the Statistica 6.0 program by cluster analysis from 1-Pearson's R Distance by using Ward's method.

DISCUSSION

Stages of Agrarian History

Starting in the early Subatlantic Period (2500 years ago), when the climate became similar to the contemporary climate, dry steppes were characterized by deposition of feather-grasses and fescues, and by the supply of plant matter and humus in the amounts of 1210 g/m^2 [14] and 5.4 MJ/m^2 per year, respectively [15].

In antique times, the Hellenes used the shifting agricultural practices which included the employment of plow implements for soil tillage. The development of viticulture in the Lower Bug region is dated back to the 4th–3rd centuries B. C.; wineries from the first centuries A. C. were discovered in Olbia [16].

If t is assumed that at the period of flourishing of antique land use the area of the lands introduced into turnover was the largest, then, according to results from analyzing aerial photographs [17], the delimitation system of the Olbia Chora (Fig. 1) encompassed an area of 29 thou ha.

The total duration of agricultural activity of the Antique Era in the key area (see Fig. 1) can be inferred from the settlements discovered here, dated 310–330 years. Settlements of the 4th–3th centuries B. C. are known to be situated in the immediate vicinities to Krestovyi ovrad as well as the nearby settlement extending along the liman shore to 700 m, dated the 5th–3rd centuries B. C. [18]. Based on using the qualitative stages of spatial development of the Olbia Chora as revealed by archaeologists [19], it is possible to determine with confidence the period of active agricultural development of lands across the study territory, namely the first quarter of the 4th – beginning

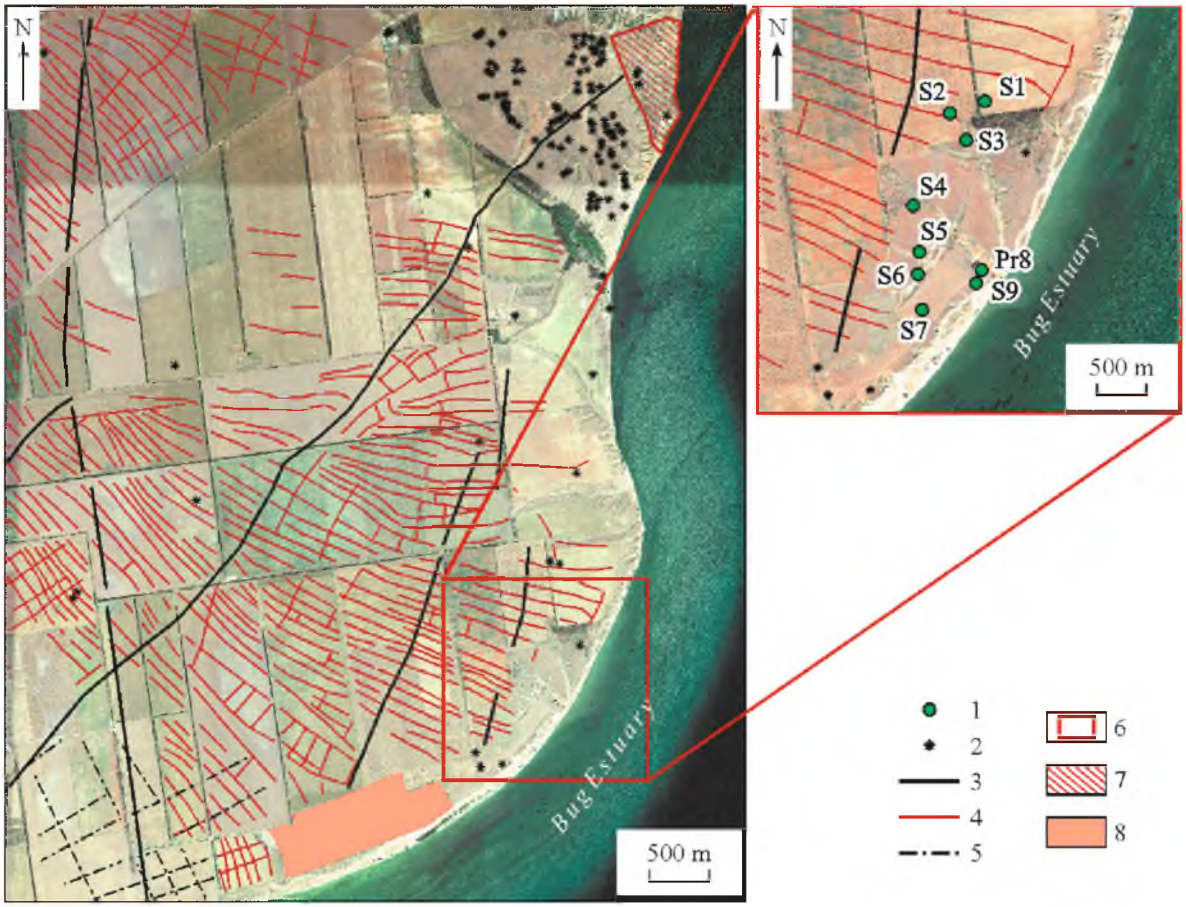


Fig. 1. Results from identifying the land-use systems at different times, to the south-west of Olbia, based on the space image taken by the Quick Bird–2 satellite (summer 2003, resolution 3 m).

(1) places of collecting: S1–S7, S9 – soil samples, Pr8 – parent rock; (2) burial mounds; (3) roads from different times of development, currently nonexistent; (4) nonlinear textures; (5) orthogonal textures; (6) key area "Krestovyi ovrag"; (7) territory of archaeological zapovednik "Olbia"; (8) territory of the contemporary village of Dneprovskoe.

of the 2nd centuries B. C.

Large-scale agricultural development of the southern neighborhood of Olbia coincides with the changes of climate which promoted the more favorable soil-formation conditions: the maximum of solar activity (Herodotus) was replaced 2350 years ago by the Greek minimum with which the period of increasing formation rates of the humus horizon of steppe soils is associated and the peak of which corresponds to 2150 years B. C. [20].

In the 19th century, this territory formed part of the Anchekrak-Parutino Zemstvo dacha, the lands of which were plowed up by 10% in 1820s and by 34% in the 1880s, with sheep-breeding predominating [21]. Shifting agriculture that had persisted until the 1850s–1860s implied that after the lands were abandoned for at least 4–5 years but for no longer than 10–15 years, they again became arable lands for 3–8 years.

The village of Dneprovskoe, the nearest to the key area, has been known since the end of the 15th century as the Turkish Sary-Kamyshi. In 1788, when the settlement was occupied by Russian troops, and to the end of the 19th century the population of the village was increasing slowly: from 9 to 30 homesteads. The proportion of plowed lands by the end of the century constituted 32%. In the 1880s, the land-use practices in this area involved formation of cells of land plots 155 sazhens in length and in width (i.e. with an area of 10.9 ha).

The development of linear erosion under the influence of the plowing up gave rise to fallow plots in the coastal zone which were difficult to involve in tillage anew. The progressive successions on the fallow lands have phytomass structure in the ground layer different from the native communities (Table 1).

Deposition of ground mortmass (R + SC) depends on the amount of maximum reserves of green mass (F), and on the decomposition rate of mortmass. The more intense the productive process, the relative measure of which is represented by F, and the lower the destruction rate, the larger is the amount of accumulated ground mortmass. The progressive successions are exceeded by the native communities dominated by feather-grass (by 8%) in its reserves and are similar to fescue

Table 1. Structure of phytomass of the ground layer in a dry steppe

Land	Plant associations	Dry weight, g/m^2			(R + SC)/F
		F	*R*	*SC*	
Virgin land	Feather-grasses	423.19	208.67	270.90	1.13
Virgin land	Fescues	228.30	222.70	226.10	1.96
Fallow	Progressive successions	246.42	242.46	198.48	1.79

Note. *F* – green phytomass; *R* – litter; *SC* – mat.

associations. The ratio (R + SC)/F represents the relationship between specific formation rates of plant matter and its destruction. According to this indicator, the post-antique fallow lands are more similar to the fescue associations than to the feather-grass ones. As was shown in [22], comparison of post-agrogenic fallow lands with virgin lands reveals the least differences for fescue associations, which points to a larger ecological correspondence of fescue to the attained maturity of the soil properties under post-agrogenic fallow lands.

In the mid-1990s, the structure of land reserves was dominated by arable lands and perennial plantations (vineyards) – 82% of the area of the entire territory; to date (by 2011), however, there appeared abandoned fields, including due to the uprooting of the vineyards. The tree-year-old fallow land S2 (see Fig. 1) is dominated y North-American introduced plants of the family of Compositae: *Xanthium albinum* (Widder) H. Scholz, and *Conyza canadensis* (L.) Cronqist.

The dominant irregular system of land delimitation traces is supplemented (partially overlapped) by a more rigorous orthogonal type of spatial organization of land use (see Fig. 1), and it was suggested that it be regarded as a multilayer model combining the analysis of synchronous and asynchronous local land-use systems [23].

The intensity of agrogenic transformation of soil (P_{at}), with its multiple use, can be determined by the suggested formula:

$$P_{at} = 100\left(1 - \frac{\sum_{1}^{n} T_i K_i}{T}\right),$$

where T_i is the duration of the period of agrogenic transformation of soils, years; T is a total duration of the agrogenic series of soils (the sum of temporal phases – virgin land, plowed land, fallow land – from 1 to n), years, and K_i is a correction coefficient of agrogenic pressure on soils. The larger the agrogenic transformation experienced by the soil, the higher the values of the indicator P_{at}. In calculations, the total duration of possible agrogenic impacts (T) was associated with the start of large-scale development of lands at the end of the archaic period of the history of Olbia's rural neighborhood (5th century B. C.), which amounted to 2500 years. The justification of the values of the correction coefficient K_i was carried out, based on the duration of the main stage of soil renaturation as a result of the progressive succession on the fallow land [24], and on the findings of regional investigations into biogeochemical transformation of plowing soils for different historical-ecological periods [15]. Thus, for the phase of the agrogenic series when the soil was in the state of virgin land, $K_i = 1$; for the extensive and intensive practices of exploitation of the plowing land, K_i is 0.49 and 0.54, respectively. For the fallow mode the value of K_i must be associated to the duration of this phase and correlated with the recovery time of vegetation which, according to [24], is taken to be 150 years for the dry-steppe conditions. Therefore, when $T_i \leq 150$ the correction coefficient of agrogenic pressure was calculated by the formula $K_i = 0.54 + (Ti/150)\cdot 0.46$, and when $T_i \geq 150$ K_i it was taken as unity.

A calculation of the indicator P_{at} for the agrogenic series of soils of the Olbia Chora is provided in Table 2.

Morphological Structure of Landscapes in the Zone of Antique Land Use

Many historical-geographical maps depict the transformation of landscapes encompassing, in the best case, two or three time periods, mostly of the last several centuries. However, the landscape of the old-developed regions reflects different-type anthropogenic impacts of many centuries, which calls for new approaches to spatiotemporal modeling. For studying the heterochronous agrolandscape systems we selected the Olbia study area (measuring 2500 ha). Its northern part is the home to the national historical-archaeological zapovednik "Olbia" under the jurisdiction of the National Academy of Sciences of Ukraine (measuring 267.5 ha) – the territory of the ancient Greek city and the necropolis.

The agrogenically caused transformation of the landscape structure was revealed by comparing the maps for the Olbia study area and a comparable territory of the current stage of development (of a duration of 120–150 years). The territory to the south of the city was always the nearby Chora of Olbia, but the degree of anthropogenic pressure on the lands was changing, which was associated with the periods of prosperity and decline of the economic life of the Polis over the course of its millennial history. According to the reconstruction of antique land use, the main areas within the Olbia study area were involved in long-lasting (as long as

Table 2. Encoding and assessment of the degree of agrogenic soil transformation (P_{at})

Object	Formula of anthropogenic modification	P_{at}
S2	VL(> 100) – ArL – lp(140) – An – FL(2100) – ArL – ext(≈ 90) – ArL-int(>40) – Vin(12) – ArL – int(4) – FL(3)	19.963
S1	VL(>80) – ArL – ext(> 100) – ArL – lp(140) – An – FL(2200) – ArL – int(31) – Vin(13) –ArL – int(5)	18.936
S6	VL(> 100) – ArL – lp(> 140) – An – FL(> 2200) – ArL – int(5) –FL(40)	15.434
S7	VL(≈ 60) – ArL – ext(140) – An – FL(2250) – ArL – int(47) –FL(3)	14.956
S3	VL(> 100) –ArL – lp(140) – An – FL(2250)	14.827
S4	VL(> 140) – ArL – lp(≈ 100) –An – FL(> 2250)	13.793
S5	VL(> 100) – ArL – lp(> 50) – An –FL(> 2300)	12.687
S9	VL(> 2500)	0

Note. Members of the agrogenic series are designated by the following symbols: VL – virgin lands; ArL – lp – arable land in antique land plots; ArL – ext – arable land of the extensive stage of utilization; ArL – int – arable land of intense utilization; Vin – vineyards; FL – fallow lands; An – FL – post-antique fallow land. The phase length in years is indicated in brackets.

700 years) agrarian development.

Results of landscape mapping of spatiotemporal territorial structures help to reveal contacts of native and quasi-native geosystems with different short- and long-term derivative modifications [2]. A fragment of the landscape map, with a respective part of the legend to it, foe the "Krestovyi ovrag" key area (5 km to the south of Olbia) is presented in Fig. 2. Krestovyi ovrag is a gully-draw system located one kilometer to the north-east of the village of Dneprovskoe. The study plot is represented by two draws with bottom gullies sharing a common mouth exiting to the Bug liman. The maximum depth of the incision of the gully reaches 35 m. The catchment of Krestovyi ovrag is favorable to soil-evolution investigations, because an active growth of the gullies promoted isolation of plateau-shaped areas forming part of the land delimitation system of the Olbia Chora and restrained the possibilities for repeated agrarian impacts on these lands.

Analysis of mapping data on the post-antique territorial systems shows their diversity in components, composition, geometry, quantitative parameters of soil cover structure and morphological structure of agrolandscapes and adjacent territories. This lends support to the view of the spatiotemporal organization of landscapes as the focus of "memory" not only of the natural-anthropogenic evolution of soil cover but also of the entire set of agrogenically caused processes governing the polychromous character of topography, soils, vegetation and other components of the geosystem.

The morphology of spatiotemporal agrolandscape systems in the zone of antique land use differs from the areas of the new type of development by a large number of components of the territorial pattern: 19 and 4–13, respectively. The differences in the characteristics of complexity are even larger. Thus, the value of the fractionality index (i.e. the ratio of the number of contours to the area of the plot) for the plots with antique prehistory of land use is by a factor of 2.6–7.8 larger when compared with the areas of the current stage of development.

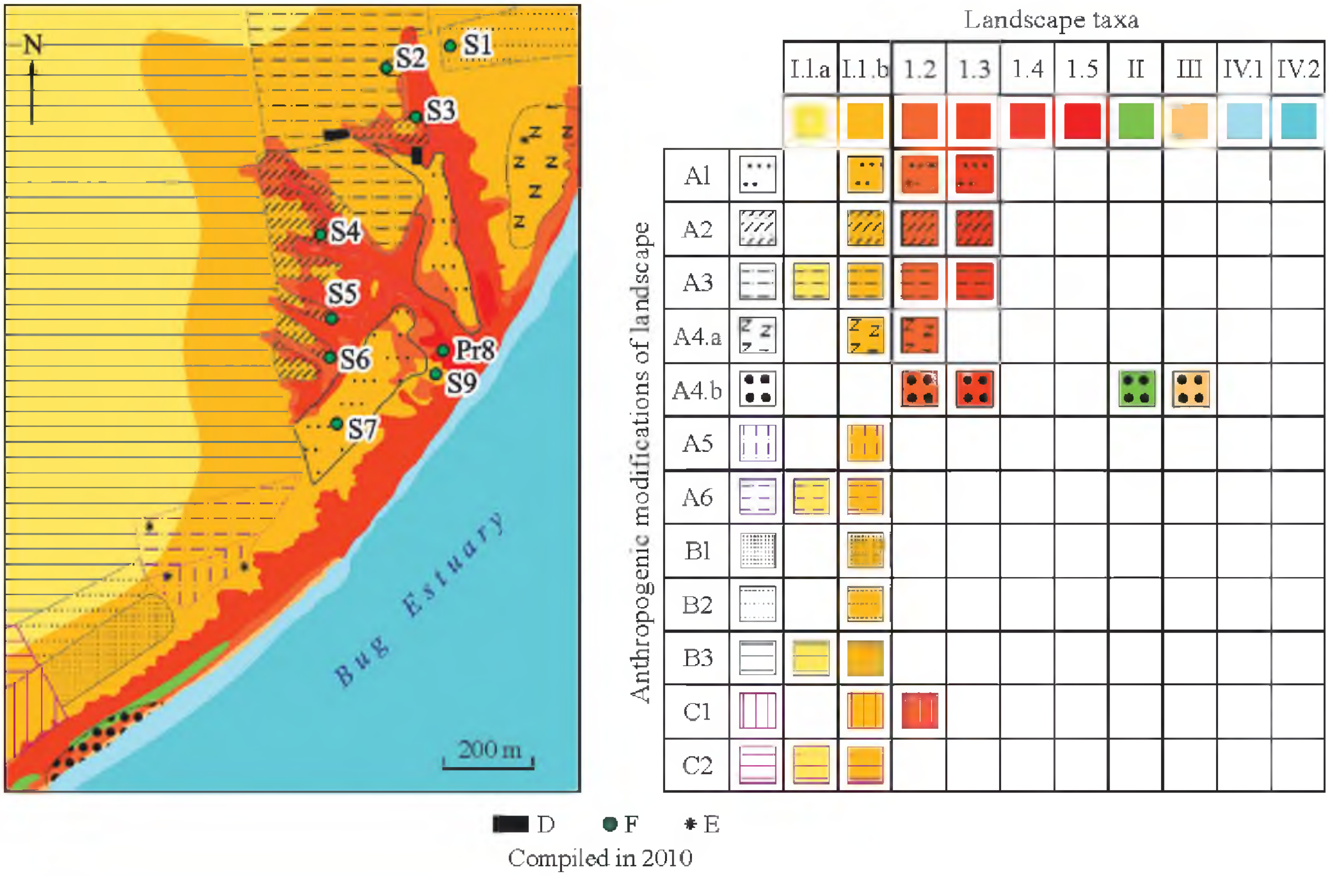
In the zone of antique land use, the branching pattern of the erosion network that is characteristic for areas of 120–150-year-long agricultural development gives way to the parallel rectangular pattern, which is largely due to the organizing principle of the antique land delimitation system.

Compared to the areas of the current stage of development, the territory of the Olbia study area exhibits a much larger ruggedness of the form of landscape contours. Within the most characteristic portion of the study area (over an area of 325 ha), 36 different-time combinations of landscape taxa and modifications were revealed among the 108 possible ones. Note that traces of the antique land-use systems are absent on the plots that were plowed up 40–55 years ago. This is attributable to the fact that the agricultural fields forming part of the Chora's land delimitation system were not in the immediate vicinity of the boundaries of the antique settlements.

Agrogenic Transformation of Soils

By summarizing the data of soil surveying from the 1960s aimed at large-scale mapping of the soil cover showed that dark-chestnut weakly solonetzic soils on loesses are characterized the humus eluvial horizon 28 cm in thickness, with the entire humus horizon totaling 57 cm in thickness. The depth of effervescence due to hydrochloric acid is observed from 56 cm, and carbonate neoformations (white soft spots) appear from 75 cm. These soils in the plowing horizon contain from 2.8 to 3.4% of humus.

Under local conditions of the study area, the dark-chestnut virgin soils contain in the upper humus-accumulative horizon 3.1% of humus (from 2.6 to 3.6%) with the ratios C:N = 10.5 and $C_{HA}:C_{FA} = 3$. The



	I.1.a	I.1.b	1.2	1.3	1.4	1.5	II	III	IV.1	IV.2
A1		▨	▨	▨						
A2		▨	▨	▨						
A3	▨	▨	▨	▨						
A4.a		▨	▨							
A4.b			▨	▨			▨	▨		
A5		▨								
A6	▨	▨								
B1		▨								
B2		▨								
B3	▨	▨								
C1		▨	▨							
C2	▨	▨								

Fig. 2. Fragment of the landscape map ("Krestovyi ovrag").

Landscape taxa: I. Weakly drained loess plains with dark-chestnut solonetzic soils and gley-solods of podsols: 1 – watershed spaces and weakly gentle slopes with dark-chestnut soils: (a) full profile, (b) weakkly washed (weakly deflated); 2 – gentle slopes with dark-chestnut weakly washed (deflated); 3 – weakly slanting, slanting and strongly slanting slopes with dark-chestnut moderately and heavily washed soils; 4 – bottoms of draws with meadow/dark-chestnut soils with forb-spurge and couch-grass/forb associations; 5 – bottom scours with pioneer groups.

II. Landslide rolling terraces under the weed-wormwood association.

III. Floodplains with contemporary liman (alluvial) shell sands.

IV. Aquatic landscape: 1 – at depths of up to 1 m, territories submerged since 1985; 2 – at depths of up to 2 m.

Anthropogenic modifications of landscape: A. Territories with restored plant cover: 1 – forming part of the zone of antique development, plowed up during the 1960s–1970s, lying fallow since 2005; 2 – forming part of the zone of antique agriculture, post-antique fallow land; 3 – forming part of the zone of antique agriculture, plowed up again during 1850s–1860s, fallow since 2005; 4 – territories of antique settlements under zonal vegetation: (a) Classic and Hellenistic time (first quarter of the 5th –mid-3rd centuries B. C.); (b) Archaic, Classic and Hellenistic time (from the 6th to the beginning of the 3rd century B. C.); 5 – fallow in the place of the former buildings for economic purposes from 1960–1985; 6 – forming part of the zone of antique land-surveying in the place of the former building for economic purposes from 1960–1985.

B. Territories under agricultural development: 1 – plowed up during the 1960s–1970s, 2 – forming part of the zone of antique agriculture and plowed up during the 1960s–1970s, 3 – forming part of the zone of antique agriculture and plowed up during 1850s–1860s.

C. Territories of contemporary settlements: 1 – not forming part of the zone of antique agriculture, 2 – forming part of the zone of antique agriculture.

(D) territories of antique country estates; (E) burial mounds; (F) places of soil (S1) and parent rock (Pr8) sampling.

post-antique fallow soils rank below the respective virgin soils by 11% rel. in humusness of the upper horizon.

The set of agrophysical, agrochemical and geochemical indicators of the state of soils totaling 53 (total chemical composition for 20 elements, Shaw's coefficient and the coefficient of eluviation, $SiO_2/(10R_2O_3)$, the entropy coefficient, Gibbs energy and lattice energy, soil density, the structure coefficient, water stability according to Savinov, water stability according to Andrianov, the diameter of water-stable aggregates, content of water-stable fraction > 0.25 mm, total carbon, group and fractional composition of humus, C/N, Cha/Cfa, content of labile forms of organic matter, phosphorus and potassium, total nitrogen, CO_2 of carbonates, and pH of aqueous and salt extracts) was subjected to statistical analysis. For this purpose, the coefficients of variation and correlation of the attributes

Table 3. Indices serving as indicators of long-term agrogenic transformation of soils of dry steppe

Indicators of agrogenic transformation of soils	Units of measurement	Numbers of objects for soil studies (see Fig. 2)							
		S2	S1	S6	S7	S3	S4	S5	S9
W	%	9	12	67	10	71	56	75	74
Water-stable aggregates > 0.25 mm	%	18.45	28.62	20.38	19.72	38.82	39.13	46.19	46.55
Cha	%	26.97	28.47	30.1	26.27	27.28	22.58	25.02	25.99
Cfa	%	18.14	9.57	11.72	10.49	12.57	15.91	16.42	8.58
N	%	0.081	0.084	0.098	0.098	0.14	0.126	0.119	0.165
P_2O_5	mg/kg	102	98	112	300	115	66	83	395
K_2O	mg/kg	112	174	75	1300	130	150	137	235
R	none	1.19	1.23	1.15	1.04	1.18	1.32	1.13	1.19
KE	none	14.10	14.45	15.32	12.95	13.52	15.60	14.02	12.57
$SiO_2/(10R_2O_3)$	none	0.58	0.57	0.65	0.63	0.62	0.60	0.64	0.62

Note. W – coefficient of water stability of aggregates; Cha, Cfa – content of carbon in humic acids and fulvoacids; N – total nitrogen; P_2O_5 – labile phosphorus; K_2O – exchange potassium; R – coefficient of accumulation; K_E – coefficient of eluviation.

were calculated followed by a content analysis and selection of the most significant parameters. As a result, the indicators were selected to be used as the indicators of a long-lasting agrogenic transformation of dry-steppe soils (Table 3).

The indicators having an indication potential for assessing the duration and intensity of soil agrogenesis (see Table 3) were included in a calculation of the geometrical mean assessment indicator of soil properties (*Sp*). Regression analysis was used to determine a dependence of the values of the generalized indicator of soil properties (*Sp*) on the intensity of agrogenic transformation of dry-steppe soils (P_{at}) (Fig. 3):

$$Sp = -66.128 + \exp(4.42 + (-0.0058 \cdot P_{at}))$$

The correlation ratio and the explained contribution from the variance were 0.93 and 0.87, respectively.

Of the first ten chemical elements which accumulate in soils relative to the parent rock (i.e., $Ka > 1$), the old arable soils, when compared to virgin soils, are distinguished by accumulation of Al_2O_3, Fe_2O_3, and Zn and by depletion of K_2O and TiO_2. In soils of the contemporary stage of development, Al_2O_3, Zn and SiO_2 accumulate in larger amounts, and the content of Fe_2O_3 decreases. In soils of post-antique fallow lands, a relative accumulation was observed for SiO_2, Fe_2O_3 and TiO_2.

The list of polluting metals was used to identify a ranked series of elements which characterize agrotechnogenic pressure: As > Ni > Fe > Cr > Cu. The higher the anthropogenic pressure experienced by the soil, the smaller the ratio of Si to the sum of the elements Al, Fe, Mn: from 5.0–5.3 in virgin and fallow soils to 4.6–4.7 in old arable soils. Because of the narrow variation of silicon ($32 \cdot 10^4$–$34 \cdot 10^4$ mg/kg), the resulting regularity is accounted for by the relative enrichment of the soil within the 0–20 cm with aluminum and, to a lesser extent, with iron.

A generalized idea of the biogeochemical changes caused by agrogenesis is provided by a cluster analysis of the series of dry-steppe soils made from the transformation coefficient of an element (the ratio of its content in soil and parent rock) (Fig. 4). The analysis used the content of 20 macro- and microelements (Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Sr, Pb, CaO Al, Si, P, K, Mg, Rb, and Na). Whilst the old-arable soils are distinguished by a high degree of agrogenic transformation, they form a special cluster.

The secondary succession (renewal of biocenoses

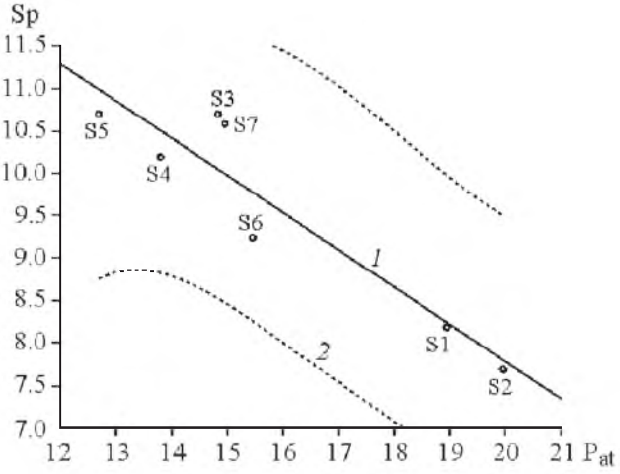


Fig. 3. Variation in summary indicator of soil properties (Sp) versus the intensity of agrogenic transformation of dark-chestnut soils (P_{at}).

(*1*) plot of the function $Sp = f(P_{at})$; (*2*) region of confidence values (0.95); S1–S7– agrogenically transformed soils whose actual characteristics (see Table 3) were used to obtain an exponential dependence through nonlinear estimation in the Statistica program.

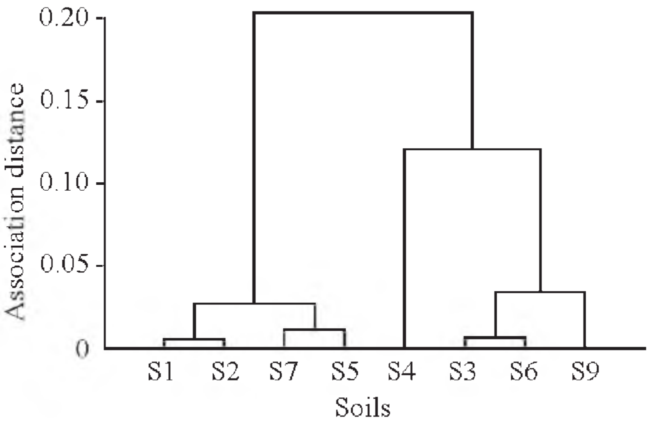


Fig. 4. Grouping of soils of the agrogenic series from the ratio of percent abundances (clarks of contents) of 20 macro- and microelements in soils to parent rock (Euclidean distance).

S1–S7, S9 – soil sample numbers.

on the regenerating soil) was assigned in [25] to the regeneration succession of the biota in the process of recent soil formation. It is thought [24] that the time taken by fallow soils in the zone of dry steppes to reach a climax varies from 100 to 150 years or more. According to out results, at a high level of threshold distances there occurs isolation of the cluster that includes post-antique fallow lands, including also those which, in their degree of restoration of geochemical properties, have approached the unmodified soils already. Consequently, even a long fallow period (over 2 thousand years) cannot remove completely from memory of soils the evidence of agrogenic impacts. Clusterization results are stable also when only accumulating elements are taken into consideration. Various chemical elements can serve as long persistent markers of agrogenesis: the necessary (for plants) macroelements (P, K) and microelements (Mn, Zn); among useful elements – Al, as well as elements of accumulation as a result of agrotechnical and biogeochemical processes (As, Pb, V, Cr).

CONCLUSIONS

The use of historical-landscape mapping of territories experiencing many centuries of agrarian development showed that cartographic models of spatiotemporal structures furnishes an opportunity to visualize the genetically-caused features of morphological structure of landscapes and their contemporary status, and through a quantitative assessment of the degree of anthropogenic modification – a retrospective of economic impacts.

The long history of anthropogenic transformations accounts for the increase in the number of spatiotemporal structures on old-developed territories. In addition, the long-lasting effects of erosion processes brought about changes in the slope subsystem of draw catchments: the width of landscape strips reached 0.3–0.4 km as distinct from 0.2–0.3 km for an analogous area of 120-year-long period of development.

In the case of a typization of agrolandscapes for a long period of development and with multiple successional changes of dominant kinds of anthropogenic influence on natural environment, it would be more appropriate not to correlate them with the contemporary kinds of lands but reconstruct the man stages of natural-anthropogenic development. To accomplish this, it is worthwhile to take advantage of the diachronic approach which includes the development of a regional historical-geographical periodization of nature management, historical-landscape mapping of the spatiotemporal territorial systems on the basis of GIS technologies, and the theoretical-experimental substantiation of the influence of the various land use practices on labile and conservative soil properties. The memory of the soils which experienced agrogenic pressures in the last retain their indicators (the totality of definite physicochemical and biogeochemical indicators). They are conserved even after the period of the fallow mode with a duration comparable to the formation time of the humus profile.

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