LAND DIVISION SYSTEM, AGROTECHNOLOGY AND SOIL TRANSFORMATION IN THE POST-ANTIQUE AGROLANDSCAPES OF NORTHWESTERN CRIMEA

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ABSTRACT

The quality of products in regions that specialize in viticulture and horticulture depends on many environmental factors, but the importance of the concentrations of trace elements in the rhizosphere is no less important than the main elements of mineral nutrition. Viticulture in ancient times played a different role in the economy of Tauric Chersonesos at the near *chora* (on the Herakleian Peninsula (South-West Crimea)) and at the distant *chora* (in North-Western (NW) Crimea). Modern climatic and soil-lithological conditions in these two regions are significantly different. The results of the study of land management practices for perennial plantations and the geochemical features of the long-term fallow soils for four regions of NW Crimea were presented. Three geographical regions in NW Crimea with different soil types in terms of content of organic matter, carbonates and elements of accumulation (Co, Pb, Cu, Cr, Ni, Ba, V) and dispersion (Si, Na, As, Zn, Zr, CaO) in the long-term fallow soils compared to untreated soils were determined according to the results of clusters analysis. Although the two regions on the Black Sea coast (Kalos Limen and Cape Ojrat), both now and in ancient times, had a different climate than the interior area (Ortli and Mamay–Tyup), soil conditions were a stronger factor of differentiation. The soils of Kalos Limen in plots with 2 types of perennial plantations of *vinea* (vine on stakes and trellises) and *arbustum* (vine on fruit trees) with a distance between the ploughing walls of 2 and 5 m, respectively, upon comparison of the content of the 13 most informative chemical elements, showed differences in Cu and Ni (accumulation) and Pb, Sr and Na (dispersion). It is assumed that in plots where the *arbustum* method was used, mechanical tillage was more regular due to the secondary use of the plots in grain farming. The root layer that was created during the laying out of the vineyard in the 4 c. BC, according to the integral biogeochemical assessment is inferior to the same layer of virgin soil by 20%. We determined the geo-

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graphical factor as the main one when comparing the geochemistry of fallow soils in individual regions of ancient viticulture of NW Crimea, which is consistent with the assessment of the role of soil in the concept of "terroir".

Keywords: antique vineyards; vineyard soil, fallow land, soil geochemistry; Crimea

INTRODUCTION

The modern experience of ampeloecological studies [1-3, et al.] shows that in addition to the terrain relief and microclimate it is important to take into account soil parameters: profile thickness, stone proportion, bulk density, Corg content and inorganic carbon etc. The formation of the vineyard vegetation cover depends largely on the content of available nutrients, especially of accessible phosphorus and essential soil properties [4]. The experience of studying the human impact on archaeological sites [5] shows that it is also very promising to characterize microbial communities, which have memory, as the soil in general. The relationships between geochemical composition and soil proprieties are usually based on estimates of the concentrations of major (SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O, P_2O_5, MnO, TiO_2) and trace elements (Cd, Co, Cu, Ni, Pb, Zn and As) in vineyard soils [6]. The geolithological features of the vineyard soil, such as concentrations of Sr, Ba, Ca, Mg, Al, K, Zn, B, Ni, Co affect the chemical composition of grape berries [3]. The role of trace elements for the grape quality is as important as the elements of mineral nutrition (N, P, K, Ca, S and Mg). According to the concept of "terroir", the soil in which grapes are grown plays a major role in the vine behavior, the grape quality, and the wine sensory characteristics [1-3]. The aim of this study was to determine the features of antique land management for perennial plantings and to establish geochemical differences of post-antique fallow land in some areas of NW Crimea.

DATA AND METHODS

Description of the study area. Traces of ancient land subdivision for horticulture and viticulture have been detected in eight areas of NW Crimea, including Kalos Limen County (4 c. BC – 2 c. AD) on the Tarkhankut Peninsula (now village Chernomorskoe). Today this area is part of the Steppe moderately hot agroclimatic region with mild winters. The region, where there was the *chora* Kalos Limen, differs from the Herakleian Peninsula (SW Crimea) by the amount of precipitation (<30 mm per year) and Σ t>10° (<324°). The last frost in spring here is 14 days earlier. These two regions still differ in viticulture conditions. If climatic conditions in NW Crimea are optimal for early varieties and medium ripening, the Herakleian Peninsula can provide the best wine materials for vintage table wines as well as strong and dessert wines of good quality. One can safely assume that the lack of heat for viticulture distinguished the NW Crimea from the Herakleian Peninsula in the ancient era as well.

Data used. The *chora* of Chersonesos includes the Herakleian and the Tarchankut Peninsula between the Karadža settlement and Kalos Limen [7]. Chersonesos through land development in NW Crimea created by the second half 4 c. BC distant *chora.* The Herakleian Peninsula (an area of about 5,000 ha) viticulture maintained the export of wine outside Chersonesos, in particular, to distant *chora* as well as to the areas of the Northern Black Sea region in 4-3 c. BC [8]. The objects of study in the distant *chora* of Chersonesos are located in the coastal area (Kalos Limen and Cape Ojrat), and in the interior area in 10 km from the sea (Ortli and Mamay-Tyup). In NW Crimea, the land was allotted for vineyards on softly sloped plains, thus avoiding northern exposure (Table 1). During the Hellenistic period, the land surveying on the entire territory of the Chersonesos State was carried out using the unified measurement system based on one stadium (210 m) [7, 8].

Table 1. Objects of study of ancient vineyards at *chora* of Chersonesos

Region	Altitude, m a.s.l.	Slope, degree	Exposition	Main (internal) size of plots	Soil*
Herakleian Peninsula	20-100 (200)	2-3(8)	SW, SE	628 × 418 (210 × 210) [9]	CNS
Kalos Limen	7-8	1-2	E	52.5 × 52.5	Cc
Ojrat	5-15	2.8	SE	210 × 210 (52.5 × 52.5)	Cc
Mamay-Tyup	2-10	0-3(2)	S, SE	220 × 270 (52.5 × 52.5)	Cc
Ortli	5-10	1-2(1.7)	WSW	210 × 210 (70 m wide strips)	CP

*CNS Cinnamonic soil; Cc Cambisols calcaric; CP Chernozem Petrocalcic.

The long agricultural history of NW Crimea opens up new opportunities for the joint study of the secondary succession of plants and soils [10], including their postagrogenic stages. Relic features of agrogenic transformations may be contained in the solid phase of the long-term fallow soils. The share of Chernozem Petrocalcic and Cambisols calcaric is 60% of the area Tarchankut Peninsula. As noted earlier [11] new qualifiers are needed, especially in the case of Calcisols, in the development of strategies related to *terroir* [12]. The concentration of 22 macroelements and trace elements (CaO, Al_2O_3, SiO_2, P_2O_5, K_2O, Na_2O, MgO, MnO, Fe, TiO_2, V, Cr, Co, Ni, Cu, Zn, Sr, Pb, Rb, Ba, Zr, As) in the vineyard soils has been determined.

Methods. The chemical properties of soils were analysed by routine methods: the Corg content, by Tyurin's method; content the CO_2 of carbonates by acidometry; the available P_2O_5 by Machigin's method. Concentration of elements were determined using the method of X-ray fluorescence analysis. Assessment of soil quality (SQ) performed by the formula: $SQ = (S_1/P_1 \cdot S_2/P_2 \cdot \ldots \cdot S_n/P_n \cdot)^{1/n}$, where S_i and P_i were content Corg and elements accumulation in soil (S) compared to its parent rock (P). Grouping of the long-term fallow soils was conducted by the method of the hierarchic classification (by Ward's method) of cluster analysis. The beginning of postagrogenic fallow land was dated through the use of data on horizon thickness A+AB within different-time archaeological sites on the Crimean Peninsula and developed mathematical model of soil evolution over time [10, 13].

RESULTS AND DISCUSSION

As with the mounds, which are clearly visible on high resolution satellite images [14], the boundaries of the allotments for grain farming are identified by photo tone, which is due to microzonal manifestation of the axial areas of the ridges and trenches in the steppe landscape (by differences in vegetation as reflection of moisture redistribution). However, in ancient vineyards the plot boundaries are not visible. Using geomagnetic survey data in the rural district of Kalos Limen, in 1.2–1.3 km to NE from settlement, we discovered an ancient land area with traces of land use for perennial plantings [15]. The land plot with area of 0.45 ha with boundaries identified during geomagnetic map interpretation is divided by texture into two parts (Fig. 1). Fig. 1B shows land plot with the division by trenching on wide (2369 m^2) and narrow plots (2122 m^2). A trench is laid from NE to SW perpendicular to the trenching walls (Fig. 1A). From the NE edge, over 55 m the average width between the five trenching walls is 10.1 m, but between walls 5 and 8, the distances narrow to 1.8 m.

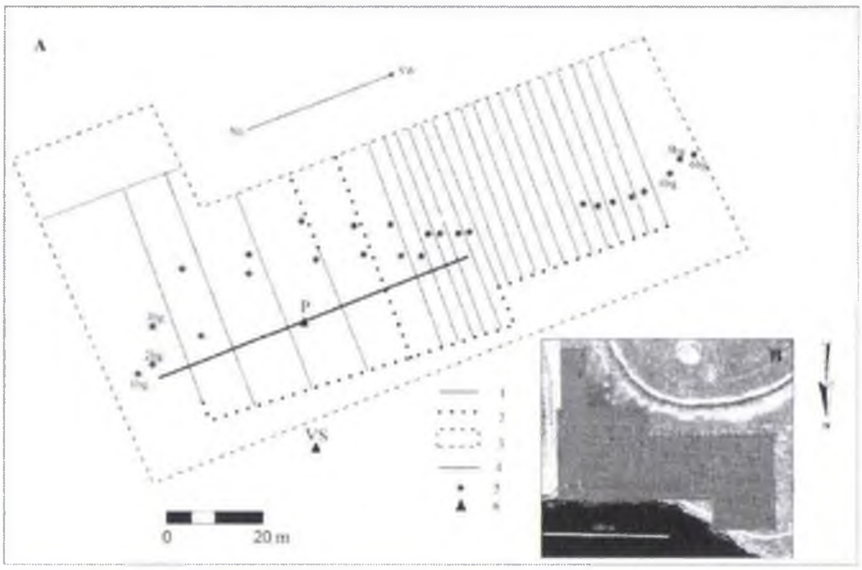

Figure 1. The results of the interpretation of land management of the ancient vineyard at Kalos Limen (A) using geomagnetic survey data (B) and soil sampling scheme. Key: trench walls along the lines of geomagnetic anomalies (1); supposed border (2); perimeter geomagnetic survey (3); stratigraphic trench (70 m) (4); soil sampling points (5); soil pits of new soil (VS) and in trench (P) (6); sampling points background soil (1bg÷6bg).

The Greeks constructed the walls for the vineyard by digging trenches to a depth of about 0.6 m and filling them with stones that are fist-sized [15]. The root layer formation based on trenching led to a change in the profile structure and soil geochemistry. Soils in broad and narrow plots (on 10 samples), background area soils and virgin soils (Fig. 1A) were the comparison objects. The ancient plot studies in the Crimea [15] showed that the land at Kalos Limen and Ojrat was originally occupied by two types of vineyards – *vinea* (vine on stakes and trellises) and *arbustum* (vine on fruit trees), which were created with the use of trenching and with inter-wall distance of 2 and 5 m respectively. Both ways mentions Columella (1 c. AD). In our case, the western half of the area consists of five wide plots, but then we have identified 17 narrow strips of average width (including trench walls) 3.09±0.18 m. Since a geomagnetic survey can show linear anomalies in the form of light lines (Fig. 1B) a more definite idea of boundaries can be obtained from descriptions in the stratigraphic pit, where by 4 walls were stripped on land plots with wide and narrow fields (Fig. 1A). The study of fallow soil along the entire length of the trench allowed us to determine the average horizon thickness A+AB. It was 364.4±1.2 mm, which according to the calculation made by pedochronological method [9], corresponds to the average date – 2,366 years (350 BC), and taking into account the range of values – from 364 to 335 BC. Virgin soil (Fig. 1A, VS) in horizon A (4–19 cm) in comparison with the parent rock (84–102 cm) it is characterized by accumulation of association elements, which can be represented as a decreasing row: $P_2O_5 > Pb > K_2O > MnO > Cu > Ba > Co > Sr > Rb > Y$ with accumulation coefficients from 1.53 to 1.10. In terms of evolution, the postagrogenic soil (Fig. 1A, P) differs from the virgin soil (Fig. 1A, VS), as having passed the natural stage of development up to the second half of the century 4 BC and renaturation from the second half of the century 3 BC in the same bioclimatic conditions it has accumulated the evidence of this effect and retained it in its properties during the agricultural period. We calculated the SQ values based on Corg content and 13 elements, which showed soil enrichment (≈ 1-10) in relation to the earth's crust (K, Sr, Zn, Al, Ti, Zr, Pb, Mn, Fe, P, Co, Ni, Cu). It has been established that the SQ (4-32.5 cm) value in the fallow soil is higher by 27 % than that of virgin soil. It means that the agricultural engineering of ancient viticulture created favourable conditions for production process in humus horizon of soils. The features of the root layer of the vineyard planted in the century 4 BC (trenching and stone sampling) are best preserved in the layer of 32-102 cm which is (according to geometric mean value calculation using 16 indicators) by 20 % worse in quality than the virgin analogue.

We found differences in accumulation and dispersion of elements by comparing the content of 13 elements with the greatest differences in wide and narrow plots compared with their background (Table 2, No bg). In comparison with narrow plots wide plot soils have a higher content of CaO, Sr, Cu, Ni and are less V, Zn, Pb, Rb, Ba enriched. Oxides, which are less sensitive to agrogenic soil transformations (SiO_2, MgO, K_2O, TiO_2, MnO, P_2O_5, Al_2O_3, Fe), show geochemical characteristics of calcium landscapes in the steppe climate of NW Crimea. It is especially important to note the geochemical specifics for those elements, which have impact on the taste of wines. The eluvium of limestone of NW Crimea (n=28) contains Fe 2.02±0.02% and Al_2O_3 8.59±0.08%, respectively. For comparison, the eluvium of limestone and *terra rossa* on Herakleian Peninsula contains common Fe 3.4 and 9.4% and Al_2O_3 9.3 and 19.7%.

Table 2. Differences in the content of chemical elements in the soil layer 0-12 cm in wide plots (WP) and narrow plots (NP) of the land mass at Kalos Limen in relation to the background conditions (bg)

Elements and oxides	Unit	WP	No 1-3bg	K*		NP	No 4-6bg	K*
Co	ppm	5.9±0.9	4.0	49.3		6.1±1.1	4.2	45.0
Pb	ppm	14.3±0.7	12.3	16.4		16.8±1.2	10.1	65.7
Cu	ppm	33.1±2.5	25.6	29.2		30.2±4.0	30.2	0.1
Cr	ppm	74.6±1.2	68.9	8.3		73.7±0.8	73.8	-0.2
Ni	ppm	39.5±1.4	36.3	8.6		37.2±1.8	39.6	-6.0
Ba	ppm	421.8±5.3	395.9	6.5		425.6±7.4	425.1	0.1
V	ppm	57.5±2.1	55.9	2.9		62.2±1.6	58.8	5.8
Sr	ppm	207.1±6.9	233.4	-11.3		203.8±6.4	193.1	5.5
Na_2O	%	1.8±0.05	2.0	-10.6		1.8±0.1	1.7	4.9
As	ppm	6.8±0.2	7.2	-6.2		6.3±0.3	7.2	-12.0
Zn	ppm	66.4±2.1	70.0	-5.1		68.7±3.8	71.9	-4.4
Zr	ppm	188.1±4.4	199.7	-5.8		186.8±2.5	189.4	-1.4
CaO	%	22.5±0.7	23.2	-3.0		20.7±0.7	21.9	-5.6

* The coefficient of differences (K, %) is calculated by the formula: 100(WP(NP))/BG)-100.

We noted higher content of Co, Pb, Cu, V and lower content of CaO, Zr, Zn and As for both types of plots as compared with the background (No bg). In comparison with narrow plots, wide plots (0-12 cm) have higher concentrations of Cu and Ni (by 9.6 and

5.9%) in soils, probably due to the influence of anthropogenic factor. The content of CaO in comparable soil layers is 22.5±0.68% (wide plots), 20.6±0.65% (narrow plots) and 19.4% (virgin soil). Taking into account the permissible parameters of $CaCO_3$ content in the Crimean fruit crop soils and our data on fallow lands we should note that such fruit crops as alycha, plum, apricot, almonds are better adapted to grow on Tarkhankut.

In their narrow plots, ancient farmers conducted the most extensive soil transformations with the use of trenches; however, lower concentration of $CaCO_3$ (on 4%) may indicate that soil cultivation was used more frequently in wide plots. It can be assumed that the period of wide plots redevelopment for grain crops took place in 290 to 280 BC. This is due to the fact that the depreciation period of fruit trees growing there was by 45-55 years shorter than that of vineyards. The assessment results of the content of those elements, which were predominantly accumulated (Co, Pb, Cu, Cr, Ni, Ba and V) and the dispersion elements (Sr, Na, As, Zn, Zr and CaO) in relation to uncultivated soils were used to diagnose differences among post-antique fallow lands in other three regions (except Kalos Limen) of NW Crimea (Table 3).

Table 3. Geochemical features of the long-term fallow soils (Horizon A) in post-antique perennial plantations, NW Crimea

Indicators	Unit	Objects *							
		1	2	3	4	5	6	7	8
Humus	%	4.19	4.32	4.86	3.4	2.64	4.14	3.75	3.52
$CaCO_3$	%	49.98	54.12	22.99	60.81	44.27	47.01	51.1	43.11
CaO	%	30.49	17.69	24.05	32.13	24.40	20.66	22.48	19.42
Na_2O	%	1.81	1.79	1.35	1.89	1.48	1.77	1.76	1.91
Sr	ppm	85.55	148.39	121.68	255.63	279.69	203.83	207.07	225.82
Ba	ppm	314.99	378.47	359.55	424.17	455.78	425.60	421.78	402.63
Zr	ppm	127.52	164.20	158.04	151.45	185.03	186.76	188.07	201.27
Cu	ppm	47.66	16.96	32.06	15.02	30.40	30.22	33.12	40.89
Zn	ppm	35.28	58.31	54.99	57.99	61.14	68.73	66.39	47.41
Cr	ppm	63.21	64.87	68.09	62.74	70.16	73.70	74.61	74.32
Ni	ppm	37.72	26.50	29.35	23.11	34.89	37.25	39.45	44.26
Pb	ppm	1.24	8.00	7.95	8.98	14.24	16.80	14.27	13.10
V	ppm	34.66	46.23	47.39	44.57	60.14	62.21	57.50	60.67
Co	ppm	0.37	1.51	0.59	2.41	6.32	6.11	5.92	8.78
As	ppm	4.54	4.40	4.84	6.97	9.82	6.32	6.78	6.02

* 1 – Ojrat: soil on plantation wall (1), vineyard soil (2), garden soil (3); Mamay-Tyup (4); Ortli; Kalos Limen (5), narrow plots (6), wide plots (7); virgin soil (VS) (8).

According to the results of clusters analysis (Fig. 2), all eight soils are clearly classified based on geographical principle. This also applies to the objects, which have been included for comparison: virgin soil near Kalos Limen (No 8) tends to Cluster III, and the soil on limestone slab from the trench wall (No 1) is adjacent to the objects of the same land plot (Cluster I). The ranked rows of accumulation of soil elements in relation to its parent rock were constructed using average values for the objects which were included in clusters: Cluster I: Cu>Ba>(V, As, Ni, Zn); Cluster II: Cu>Co>Pb>V>Cr; Cluster III: Cu>Pb>Ni>As>V>Zr>Zn>Cr>Ba. It was noted that soils from Cluster III (nine elements have higher in-soil content than its parent rock, including the association of heavy metals) have the greatest geochemical diversity. As compared with the soils on

Cape Ojrat the soils which are included in Cluster III (Kalos Limen) have higher contents of V, Zn and Ni and particularly significant concentration of Sr, Ba and Zr. The soils being part of Cluster II (Ortli and Mamay–Tyup) differ from those of Cluster I in higher Sr and Ba content and lower Cu content.

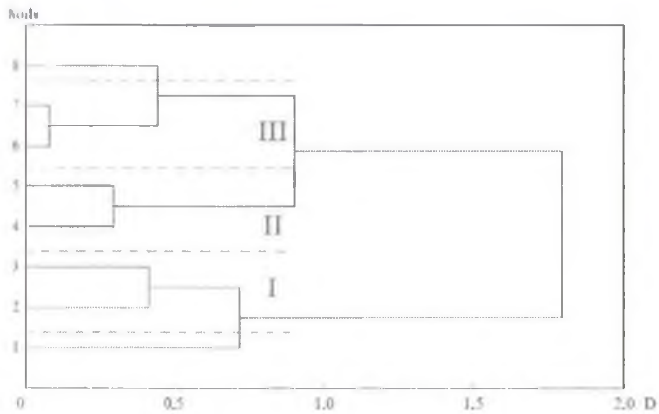

Figure 2. Dendrogram of clusters analysis of the long-term fallow soils in four regions of NW Crimea by the content of 15 soil parameters. D is Linkage distance; I–III clusters. No soils (1÷8), see note to the Table 3.

CONCLUSIONS

The results of the pedochronical studies have shown that land surveying at Kalos Limen and the construction of vine trenching coincided with the "Chersonese" cultural-historical period of the formation of this antique centre. In NW Crimea, given the widespread use of Cambisols calcaric on such sites as Kalos Limen and Ojrat in addition to *arbustrum* vineyards one can assume the profile of ancient horticulture from sunflower seeds (apple tree, pear) and stone cultures (plum, cherry plum, apricot) as well as almonds and walnuts. The expected more significant impact of agricultural engineering on geochemical transformation of soils within narrow plots (2 m) of the ancient vineyard as compared to plots of 10 m wide was not justified. Higher concentrations were observed for the association of elements in soils as compared to their background, which can be presented as a descending row: Co>Cu>Pb>Ni>Cr>Ba>V (wide plots) and Pb>Co>V>Sr>Na (narrow plots). The geochemical characteristics of the root layer (32-102 cm) which was created during vineyard planting in the century 4 BC made it possible to assess the quality of the fallow soil: it turned out to be lower than in the virgin soil by 20 %. This allows using informative biogeochemical indicators of agrogenesis to diagnose the existence and overall intensity of agriculture in rural districts of ancient settlements. The obtained results showed that the conservative soil properties in the form of geochemical associations could act as indicators of agrogenic transformations under the influence of ancient land use practices. The integral geochemical characterization of fallow soils which were used for perennial plantings in the ancient era (4-2 c. BC) in four regions of NW Crimea has shown geographical factor priority, which is consistent with assessment of role of the soil according to the concept of "terroir".

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