DOI: 10.15201/hungeobull.72.3.1 Hungarian Geographical Bulletin **72** 2023 (3) 209–222.

Comparative characteristics of the meadow soils of the Crimean mountain plateaus

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Abstract

The results of studies of mountain-meadow soils of the Crimean Mountain plateaus (yailas) within the range of heights from 580 to 1,493 m a.s.l. are presented. The aim of the research is a comparative analysis of the full-profile soils of the mountain meadows distributed on the western and eastern parts of the Main Ridge of the Crimean Mountains and their correspondence to similar soils of nearby mountain ranges. According to the results obtained, the soils of the western yailas are classified as Phaeozems and Umbrisols, while the eastern ones are mostly classified as Chernic Phaeozems. Chernic Phaeozems differ from Phaeozems and Umbrisols by higher values of the humification rate and the optical density of humic acids. In the humus horizons of Phaeozems and Umbrisols, the average values of the of humification rate varied from 21 to 31 percent, and Chernic Phaeozems from 27 to 34 percent. The optical density varied from 12.7 to 18.7 in Phaeozems and Umbrisols, and from 22.2 to 24.2 in Chernic Phaeozems. The climatic feature of the western yailas is the predominance of winter precipitation, or their relatively uniform distribution between warm and cold seasons, while at the eastern yailas the precipitation of the warm season prevails which may be responsible for the revealed differences in soil properties.

Keywords: Phaeozems, Chernic Phaeozems, Umbrisols, climate, acidity, humus state

Received October 2022, accepted June 2023.

Introduction

The soils of mountain meadows are formed on the plateau or *yailas* (mountain pastures) of the Main Ridge of the Crimean Mountains, having a total area of about 346 km² and confined to the heights of 600–1,545 m a.s.l. These massifs are mainly composed of marble-like limestone and partly conglomerates of Upper Jurassic age (Yena, V.G. *et al.* 2007). The southern part of Crimea belongs to the northern edge of the territory with a Mediterranean climate also classified as hot dry-summer climates or Csa according to the Köppen-Geiger classification (Peel, M.C. *et al*. 2007).

The first mention of mountain-meadow soils we found in Bogoslovsky, N.A. (1987), who described soil on the Ai-Petri plateau, similar in colour and profile structure to the chernozem, but completely leached of carbonates. In subsequent decades, the morphology, the main physical, physical-chemical and chemical properties of mountain-meadow soils were studied and the first attempts to classify them were made (Antipov-Karataev, I.N. and Prasolov, L.I. 1932; Klepinin, N.N. 1935; Mikhailovskaya, O.M. 1939; Kochkin, M.A. 1967; Polovitsky, I.Y. and Gusev, P.G. 1987; Dragan, N.A. 2004).

In recent years, interest in the soils of mountain meadows of the Crimea signifi-

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cantly decreased, so in the literature, very little information can be found about the current state of the soils of the mountain plateaus, large areas of which are subject to transformation under anthropogenic pressure (Kostenko, I.V. 2018).

Taking into account the period in the most of the research has been carried out, the questions of diagnosis and classification of such soils according to the modern soil classification systems remain unresolved up to the date. As a result, the authors could refer to the soils of the same territories as different types (Antipov-Karataev, I.N. and Prasolov, L.I. 1932; Klepinin, N.N. 1935; Mikhailovskaya, O.M. 1939; Kochkin, M.A. 1967), since the criteria for their diagnostics had not yet been developed.

According to the Classification and Diagnosis of Soils of the USSR (1977) the meadow soils of the cold and moist mountain regions of temperate latitudes (alpine and subalpine zones) under mesophilic meadows were referred to type of mountain-meadow soils characterized by high acidity, low base saturation, and high soil organic matter (SOM) content. These soils cover the peaks and slopes of mountain ridges and are formed on unsaturated sialitic weathering products of dense sedimentary and massively crystalline rocks. Among them, less acidic and more saturated dark-coloured soils are distinguished, which are formed on leached eluvium of carbonate rocks.

The meadow soils of the temperate humid mountain regions on leached eluvium of carbonate rocks were referred to mountain-meadow chernozem-like soils. Their main features are the closed to black colour of humus horizon with high SOM content, medium acidity and base saturation, and no secondary carbonates in the soil profile.

According to the World Reference Base (WRB) for soil resources (IUSS Working Group WRB, 2015), the soils of mountain meadows with dark, humus-rich surface horizons, which are free of secondary carbonates and less rich in bases in comparison with Chernozems should be referred to Phaeozems. Phaeozems cover the order of 190 million ha worldwide, mainly in the humid and subhumid parts of the plains (WRB, 2015), and in many countries of the Mediterranean region (Soil Atlas of Europe, 2005; Zdruli, P. *et al*. 2010). The mountain-meadow chernozem-like soils should be referred to as the Chernic Phaeozems, a soil with a thick, well-structured, very dark-coloured surface horizon that is the special case of the mollic horizon (WRB, 2015). Chernic Phaeozems are typical for the forest-steppes of plains (National Atlas of Soils of the Russian Federation, 2011; Chizhikova, N.P. *et al*. 2018; Rukhovich, D.I. *et al*. 2018; Mendyk, L. *et al.* 2020; Tóth, T. *et al*. 2022), where Phaeozems are neighbour to Chernozems and occur in depressions with additional runoff that intensifies leaching of carbonates beyond the Luvic horizon of soils (Khitrov, N. *et al*. 2019). There are some evidences on the distribution of Chernic Phaeozems in Botswana's tropics and subequatorial Tanzania (Romanens, R. *et al*. 2019; Jackson, Z. 2021).

The soils with dark, humus-rich surface horizons, but high in acidity and low in bases, should be referred to Umbrisols. These soils develop on weathering material of siliceous or strongly leached basic rocks in the humid climate of mountainous region (Dumig, A. *et al*. 2008; Miechówka, A. *et al.* 2021; Zech, W. *et al.* 2022). In the Mediterranean Umbrisols occur mainly in some regions of Portugal, Spain, and Italy and occasionally are found in the Balkans (Lässiger, M. *et al*. 2008; Zdruli, P. *et al*. 2010; Costantini, E.A.C. *et al*. 2013a; Carballas, T. *et al*. 2016). In the Bieszczadi Mountains of Poland Umbrisols are spread at an elevation about 1,200 m with a mean annual temperature 4 °C and precipitation rate of 1,200–1,300 mm (Musielok, J. *et al*. 2019). These climatic conditions are very close to those of the Crimean Mountains above 1,400 m a.s.l., so Umbrisols may be found above this elevation on the strongly leached products of solid limestone weathering that are the dominant parent rock of the Main Ridge of the Crimean Mountains (Kochkin, M.A. 1967).

The research aims to compare the full-profile soils of the mountain meadows distributed on the western and eastern parts of the Crimean Mountains and their correspondence to similar soil groups of nearby mountain ranges.

Materials and methods of investigation

The studies were conducted on the western yailas of the Main Ridge of the Mountainous Crimea: Baydar, Ai-Petri, and Gurzuf, as well as on Chatyr-Dag and Dolgorukov yaila, which are part of the system of eastern yailas *(Figure 1).* The range of heights in the places of soil sampling varied from 580 m a.s.l. on the Baydar yaila and up to 1,493 m on the Gurzuf yaila.

The modern relief of the yailas was formed under the influence of karst processes, the action of which led to the formation of a hilly surface with many depressions filled with weathering products of the Upper Jurassic limestone. The thickness of the aluvial-deluvial deposits varies in depressions from 60 to 150 cm, and the thickness of the eluvium on the elevated parts of the plateau rarely exceeds 50–60 cm (Kochkin, M.A. 1967).

Climatic conditions in the Crimean Mountains are well studied due to the presence of dozens of meteorological observation points, which functioned in the entire range of altitudes of the Main Ridge (see Scientific and Applied Reference Book on Climate of the USSR, 1990). Precipitation and temperature were closely correlated with altitude ($R^2 = 0.83–0.98$), which made it possible to calculate the values of climatic indicators for the objects of research using regression equations *(Table 1).*

Despite the average annual rainfall of the western and eastern parts of the Main Ridge being close, they differ greatly in the sea-

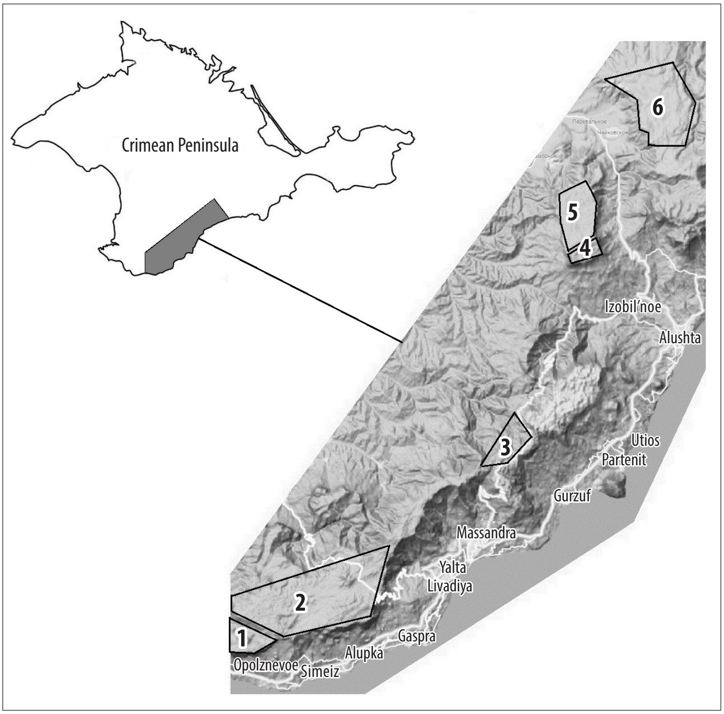

Fig. 1. Location of the research objects (yailas) within the Main Ridge of the Crimean Mountains. 1 = Baydar; 2 = Ai-Petri; 3 = Gurzuf; 4 = Upper Chatyr-Dag; 5 = Lower Chatyr-Dag; 6 = Dolgorukov

*Table 1. Hydrothermal conditions in the places of soil pits**

Profile number, part of the Main Ridge	Temperature, °C			Precipitation, mm		
	XI–III	IV–X	I–XII	XI–III	IV–X	I–XII
Baydar yaila						
1370, Western	0.0	19.6	9.3	423	383	806
Ai-Petri yaila						
1251, Western	–3.6	15.5	5.8	648	404	1,052
Gurzuf yaila						
1385, Western	–5.6	12.1	4.3	506	555	1,061
Upper Chatyr-Dag yaila						
1361, 1369, Eastern	–5.1	13.4	4.7	439	590	1,029
Lower Chatyr-Dag yaila						
1306, Eastern	–2.7	16.8	6.7	420	590	1,010
Dolgorukov yaila						
1372, Eastern	–2.2	17.7	7.3	416	495	911

*According to calculated data.

sonal redistribution. According to the calculated data (see *Table 1*), in the western part, precipitation of the cold season dominates which is typical to the Mediterranean climate (Aschmann, H. 1973), while in the eastern part, most of the precipitation falls in summer.

Meadow steppes, which occupy most of the open spaces of the plateau, form the basis of the Crimean yailas vegetation cover. Tree vegetation on the yailas, except for the lowest Baydar yaila, is fragmentary, confined to the relief elements, protected from the adverse effects of strong winds (Plugatar, Yu.V. 2015). The vegetation composition of meadow steppe communities of the western yailas in the research sites is generally similar to the species composition of the eastern ones (up to 75% of the total species in the plant communities), but there are significant differences in the dominant between them. Thus, *Cariceta humilis* formation is typical for the western yailas and Chatyr-Dag meadow steppe, while *Festuceta callieri* is typical for the eastern part of the Main Ridge.

Soils were described and sampled under meadow vegetation in depression and on the gentle slopes where no sights of soil material washout were observed. These soils were developed on leached skeleton-free weathering products of dense Upper Jurassic limestone. Samples were obtained in continuous order along the entire profile every 10 cm.

In soil samples, pH in KCl suspension was determined at the soil-to-solution ratio 1:2.5; the soil organic carbon (TOC) content was determined according to the dichromate titration method (Walkley, A.J. and Black, I.A. 1934; Kogut, B.M. and Frid, A.S. 1993). This method is aimed for classical organo-mineral soils, thus, we have used it in our work (Polyakov, V. *et al.* 2017). Humic acids (HA) were isolated according to the IHSS protocol (Swift, R.S. 1996 – https://humic-substances.org/isolation-of-ihss-soil-fulvic-and-humic-acids/), were determined by wet digestion method with colourimetric determination of organic carbon according to Practical Guide to Agrochemistry, 2001 (edited by Orlov, D.S. and Grindel, N.M., in Russian); the optical density of the HAs was measured in a solution diluted to a carbon concentration of 50 mg/L ($Ec^{mg/ml}$) with colourimetric determination at a wavelength of 430 nm (Plotnikova, T.A. and Ponomareva, V.V. 1967). The humification rate (HR) of organic matter (OM) was calculated as the percentage of carbon of HA from TOC (Grishina, L.A. and Orlov, D.S. 1978). Particle size distribution was determined by pipette (sedimentation) method with pyrophosphate dispersion of samples (Shein, E.V. 2001); exchange acidity (H^{+}+Al^{3+}) (Exac) by alkaline titration of 1 M KCl extract; exchange Al^{3+} (Alex) in this extract by colourimetric method with xylene orange; hydrolytic acidity (HAc) according to the modified pH-metric method of Kappen (Yagodin, V.A. *et al.* 1987). The degree of base saturation (BS) was calculated as a percentage of Ca^{2+}+Mg^{2+} from their sum with HAc. The content of dithionite-soluble (non-silicate) iron (Fe_{dit}) was determined according to Coffin; oxalate-soluble (Fe_{ox}) according to Tamm (Zonn, S.V. 1982). Soil optical properties were studied by scanning the wet samples applied to a transparent film (Kostenko, I.V. 2014; Kostenko, I.V. and Opanasenko, N.E. 2020). RGB colour model values were calculated for the obtained scans and used for statistical calculations and visualization of soil horizon colours. The relationship between colour intensity and RGB values is inverse; therefore, the darker the soil, the lower the RGB values.

Statistical analysis

The statistical analysis for a large number of samples was performed using the STATISTICA 6 package. Multiple linear regression analysis was used to establish the main soil factors affecting soil colour intensity, presented as R-RGB values. To demonstrate differences in the effect of organic matter on the colour of chernic and umbric or mollic soil horizons TOC content was plotted against R-RGB values.

Results and discussion

Most of the territory of the Baydar yaila (see *Figure 1*) is covered with forest vegetation, so the full-profile meadow soils were found in a closed depression of about 6 ha, confined to the southern part of the plateau. Such an extensive meadow-steppe area is the only one for this elevation range within the Main Ridge of the Crimean Mountain. The main reason for the formation of a meadow-steppe ecosystem within the depression is the close groundwater table (Nikiforov, A.R. and Kostenko, I.V. 2019), which creates a competitive advantage for the growth of herbaceous species. A similar introduction of the meadow ecosystem into the mountain forest belt under the influence of a complex of external factors has been observed in other mountain regions (Munroe, J.S. 2012). The located within a depression soil profile of Phaeozem 1370 *(Figure 2, Table 2)* consisted of a dark grey with a brownish tint Ah horizon, greyish brown AB horizon, brown with a greyish tint B horizon underlain by pale-brown, carbonate (2% $CaCO_3$) BC horizon. The granular structure was observed in the humus layer of soil while subangular in Bw and BC horizons. The profile was slightly differentiated in texture, so the Bw horizon did not match the criteria of an argic horizon. Within the leached part of the profile, the soil was slightly acidic, deeper – neutral with a high degree of saturation with bases. Fe_{dit} content increased with depth as clay content increased, and Feox content decreased *(Table 3).* The HR of organic matter corresponded to the "average" level, according to Grishina's and Orlov's classification (1978). The values of $Ec^{mg/ml}$ in the Ah horizon were significantly lower compared to the soils of the eastern part of the Main Ridge *(Table 4).*

Ai-Petri yaila is one of the largest plateaus of Crimea, with a very diverse mountain landscape and soils. But in the 20th century, after the construction of the road from Yalta to Bakhchisarai across the plateau, the vegetation and soil cover of yaila was exposed to unfavourable anthropogenic impact for a long time. The most fertile soils were actively exploited as farmland, and then most of them were afforested with *Pinus Sylvestris L.* The preserved meadow areas are still regularly mowed, despite the protected 1974 status of the plateau. Up to date, only small areas of meadows adjacent to natural and artificial forest plantations have remained outside of anthropogenic influence, one of which has been used for soil research.

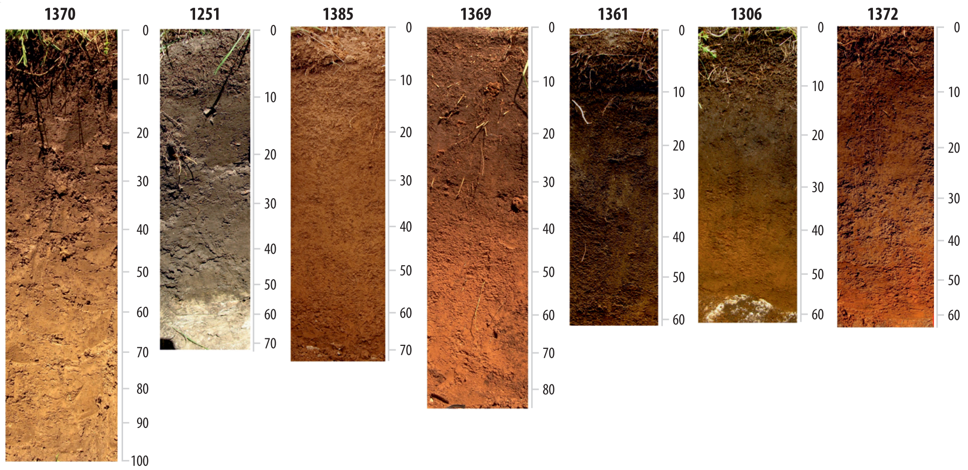

Fig. 2. Profiles of Phaeozems (1370, 1251), Umbrisols (1385, 1369), and Chernic Phaeozems (1361, 1306, 1372) of the Crimean Mountain plateaus

Table 2. Characteristics of the research objects

Profile number, Height a.s.l.	Plateau, relief, plant association, coordinates	Soil types, according to WRB, 2015
1370 580 m	Baydar yaila, sink bottom, *Briza media* + *Poa pratensis* + *Festica pratensis,* 44°25,390´N, 33°50,552´E	Calcaric Leptic Phaeozem (Clayic)
1251 1,122 m	Ai-Petri yaila, plateau, *Arrhenatherum elatius* + *Elytrigia repens,* 44°28,469´N, 34°0,953´E	Cambic Endoleptic Rendzic Phaeozem (Clayic)
1385 1,493 m	Gurzuf yaila, plateau, *Carex humilis* + *Festuca callieri,* 44°35,336´N, 34°12,334´E	Luvic Leptic Umbrisol (Clayic)
1361 1,379 m	Upper Chatyr-Dag, hollow bottom, *Poa pratensis* + *Persicaria bistorta* + *Alchemilla tytthantha,* 44°44,979´N, 34°18,821´E	Luvic Leptic Chernic Phaeozem (Clayic)
1369 1,394 m	Upper Chatyr-Dag, hollow bottom, *Phleum pratense* + *Poa pratensis,* 44°44,886´N, 34°18,332´E	Luvic Leptic Umbrisol (Clayic)
1306 961 m	Lower Chatyr-Dag, slope 10°, *Festuca callieri* + *Elymus reflexiaristatus,* 44°47,789´N, 34°17,170´E	Luvic Leptic Chernic Phaeozem (Clayic)
1395 846 m	Dolgorukov yaila, hollow slope 4–6°, 44°51.918´N, 34 21.942´E	Retic Chernic Phaeozem (Epiloamic, Endoclayic)

The profile of Phaeozem 1251 (see *Figure 2,* and *Table 2)* included a dark grey, loose, leached Ah horizon sharply transitioning to a light grey with olive shade C horizon of soil-forming rock consisting of the debris of marl, which contained an average of 42 percent carbonates. The granular structure was recognized in Ah horizon which is typical for humus-rich upper soil layers. The occurrence of loose marl directly under the Ah horizon caused its low acidity and high BS (see *Table 3).* The described soil was somewhat inferior to the virgin soil of profile 1370 in the content of TOC in horizon Ah, but due to the greater thickness of the humus horizon,

Table 3. Morphology, physical and chemical properties of analysed soils

Profile	Horizon	Depth, cm	Colour, moist	Structure*	Textural class	pH_{KCl}	Ca^{2+}+Mg^{2+}	HAc	Exac/Alex	BS,	Fe_{dit}	Fe_{ox}
							cmol + kg-1			%	mg/100 g	
1370	Ah	0–10	2.5Y 2.5/1	G	Silty Clay Loam	5.65	31.0	4.4	–	88	1,548	460
	A	10–30	2.5Y 4/1	G	Silty Clay Loam	5.66	29.6	3.9	–	88	1,709	391
	AB	30–50	5Y 4/2	G	Silty Clay	5.81	28.9	2.1	–	93	1,906	199
	Bw	50–80	5Y 6/2	SB	Silty Clay	6.15	28.5	1.1	–	96	1,957	126
	BC	80–100	5Y 6/3	SB	Silty Clay	6.92	–	–	–	–	1,947	83
1251	Ah	0–10	2.5Y 2.5/2	G	Silty Clay	5.66	35.2	4.0	–	90	–	–
	A	10–50	5Y 3/1	G	Silty Clay	5.50	35.8	3.9	–	90	–	–
	C	50–80	2.5Y 6/2	SB	Silty Clay	–	–	–	–	–	–	–
1385	Ah	0–10	2.5YR 4/1	G	Silty Clay Loam	4.06	13.3	14.2	3.02/2.11	48	2,585	428
	A	10–30	2.5Y 4/3	G	Silty Clay Loam	3.90	10.4	15.1	7.42/5.90	41	2,684	414
	AB	30–50	2.5Y 5/4	G	Silty Clay	3.86	13.3	13.8	7.53/6.46	49	2,692	294
	Bt	50–70	2.5Y 4/3	SB	Silty Clay	3.93	23.2	10.7	4.27/3.22	68	2,808	235
1361	Ah	0–10	2.5Y 3/1	G	Silt Loam	4.48	25.1	13.1	1.52/1.68	66	1,860	568
	Ah1	10–30	2.5Y 3/3	G	Silty Clay Loam	4.11	19.4	13.3	2.91/2.21	59	2,026	585
	ABt	30–50	2.5Y 5/4	SB	Silty Clay	4.11	21.0	10.8	2.28/1.94	66	2,140	462
1369	Ah	0–10	7.5YR 2.5/1	G	Silt Loam	3.92	14.8	16.4	2.43/1.51	47	1,869	441
	A	10–30	7.5YR 4/1	G	Silty Clay Loam	3.78	10.7	15.4	6.30/5.43	41	2,050	411
	AB	30–50	7.5YR 4/3	G	Silty Clay	3.71	10.8	15.6	8.75/7.93	41	2,120	273
	Bt	50–80	7.5YR 4/4	SB	Silty Clay	3.79	21.5	10.1	4.90/4.01	68	2,103	174
1306	Ah	0–10	5Y 2.5/1	G	Silt Loam	4.54	36.1	13.8	0.30/0.12	72	1,956	317
	Ah1	10–30	10YR 2/1	G	Silty Clay Loam	4.07	29.6	15.3	2.20/1.56	66	2,240	322
	Bt	30–50	10YR4/4	SB	Silty Clay	4.15	31.4	8.5	1.70/1.28	79	2,183	187
1395	Ah	0–10	5 YR 2.5/1	G	Silt Clay Loam	4.95	28.4	8.7	–	77	2,232	338
	Ah1	10–40	5YR 2.5/1	G	Silt Clay Loam	4.61	24.7	9.7	–	72	2,328	334
	AB	40–60	2.5 YR 4/3	SB	Silt Clay Loam	4.48	18.5	6.0	–	76	2,056	262
	Bt	60–100	5 Y 6/2	AB	Silty Clay	4.43	25.6	4.8	–	84	2,241	263

*Structure: G = granular, SB = subangular blocky, AB = angular blocky.

Table 4. Indicators of humus status and optical characteristics of mountain meadow soils of the Crimea

Profile	Horizon	Depth, cm	TOC	HR	$Ec^{mg/ml}$	R	G	B	Colour of soil samples
			%						
1370	Ah	0–10	5.92/38.6*	21	11.5	60	52	29	■
	A	10–30	4.13	23	14.6	69	60	35	■
	AB	30–50	1.86	22	17.8	90	78	46	■
	Bw	50–80	1.09	17	20.0	117	102	57	■
	BC	80–100	0.95	–	–	105	92	54	■
1251	Ah	0–10	5.31/41.0	21	16.9	58	47	18	■
	A	10–50	3.42	25	17.5	64	54	34	■
	C	50–80	0.81	22	15.9	136	118	77	■
1385	Ah	0–10	5.19/30.1	27	10.9	64	46	17	■
	A	10–30	2.67	32	13.0	75	54	20	■
	AB	30–50	1.71	30	10.1	94	70	31	■
	Bt	50–70	1.01	33	5.6	108	77	35	■
1361	Ah	0–10	11.3/63.5	24	17.7	27	20	4	■
	Ah1	10–30	6.16	28	24.4	35	24	5	■
	ABt	30–50	2.93	24	24.0	64	46	16	■
1369	Ah	0–10	8.84/45.3	18	15.8	44	32	12	■
	A	10–30	4.43	22	20.1	56	43	19	■
	AB	30–50	1.67	18	16.2	87	62	26	■
	Bt	50–80	0.89	8	7.1	107	74	34	■
1306	Ah	0–10	7.45/38.7	30	18.1	27	19	4	■
	Ah1	10–30	3.61	36	26.6	34	23	7	■
	Bt	30–50	1,64	16	19.0	88	60	23	■
1395	Ah	0–10	8.79/52.5	32	18.2	26	17	4	■
	Ah1	10–40	4.82	46	21.8	30	21	6	■
	AB	40–60	1.10	46	26.0	71	48	17	■
	Bt	60–100	0.78	29	14.8	105	67	26	■

*SOM stocks in the layer of 0–50 cm, kg/m^2.

it surpassed it in the total organic matter stocks in the 0–50 cm layer. Both soils had practically equal HR, but the soil of profile 1251, formed in colder and wetter conditions, was distinguished by higher values of $Ec^{mg/ml}$ and due to this, a slightly greater intensity of colouring of Ah horizon (see *Table 4*).

Gurzuf yaila is a part of the Crimean Natural Reserve, where soils are subject to much less anthropogenic influence compared to mountain plateaus outside of protected areas. On the other hand, the reserve status contributes to the constant growth of the wild boar population, which regularly destroys the sod layer, interrupting the normal course of the soil-forming process.

Located in a small depression on Gurzuf yaila, the profile of Umbrisol 1385 (see *Figure 2*, and *Table 2*) consisted of grey with brown tint Ah horizon, brown with grey tint AB horizon and brown Bt horizon underlay by a mixture of limestone debris with clay. The texture class of this Umbrisol varied from Silty Clay Loam to Silty Clay, so the Bt horizon met the criteria of argic horizon. A granular structure was observed in the humus layer of soil while subangular in the Bt horizon. This soil was formed in the coldest and most humid conditions at the top level of the Crimean Mountains, promoting the intensive leaching of carbonates and bases. As can be seen from the data in *Table 3*, the pH values of the described soil are markedly lower compared to the soils of Baydar and Ai-Petri yailas, and HAc respectively higher, which along with the low bases content caused the BS within most of the profile less than 50 percent. Exac also reached high values, the proportion of Al^{3+} in which ranged from 70 to 85 percent (see *Table 3*). The content of Fe_{dit} and Fe_{ox} in Umbrisol of Gurzuf yaila was much higher as compared to Phaeozem of Baydar yaila *(*see *Table 3).*

TOC in profile 1385 was lower than in the profiles of 1370 and 1251. In addition to the relatively low humus content, the organic matter of profile 1385 was characterized by very low values of $Ec^{mg/ml}$. The combination of these factors caused a lower colour intensity of Ah horizon in comparison with the soils of the Baydar and Ai-Petri plateaus *(*see *Table 4).*

The soils described above occur within a single mountain range, which stretches from the Baydar valley in the northeast direction for about 50 km along the south-eastern coast of Crimea and is contingently divided into separate yailas. Chatyr-Dag and Dolgorukov mountain ranges are located apart and separated from the western part of the Main Ridge by deep gaps *(*see *Figure 1).*

Chatyr-Dag is divided into upper and lower plateaus, both of which are part of the Crimea Nature Reserve. The upper plateau rises about 300 m above the lower one and, unlike the rest of the Crimean yailas, is available only for hiking that contributed to the preservation of soils in their original state.

In a small hollow on the upper plateau of Chatyr-Dag, profile 1361 of Chernic Phaeozem was studied *(*see *Figure 2,* and *Table 2).* It consisted of a dark grey, close to black in the wet state Ah, and greyish-brown AB horizons, underlain by limestone debris. Granular and subangular structure was observed throughout the profile. The texture class of the soil varied from Silt Loam in the Ah horizon to Silty Clay at the bottom, indicating the presence of the Argic horizon in the lower part of the profile *(*see *Table 3).* According to the values of pH, HAc, and Exac/Alex, this soil is more acidic compared to Phaeozems of Baydar and Ai-Petri yailas because it was formed in conditions of excessive moisture at the height of more than 1,400 m a.s.l. *(*see *Table 1).*

The content of TOC and stocks of SOM in the 0–50 cm layer of Chernic Phaeozem, as well as HR and $Ec^{mg/ml}$ values, greatly exceed these soil indicators in Phaeozems of 1370 and 1251 soil profiles. Due to a combination of these factors, the Ah horizon of 1361 soil profile had a more intense colour compared to the soils of the western yailas *(*see *Table 4).*

In a deeper and wetter hollow 650 m west of the Chernic Phaeozem, the profile of Umbrisol was described (*Table 2*, profile 1369). It consisted *(*see *Figure 2)* of dark grey with brown tint Ah horizon, followed by brown with grey tint AB and brown Bt horizons, underlain by limestone debris *(*see *Table 3).* The granular structure was observed in humic and subangular in Bt soil horizons. The texture class was similar to the profile of Chernic Phaeozem. This soil was formed in wetter conditions than Chernic Phaeozem, so it was characterized by higher values of acidity and very lower values of BS, which are more typical for the forest of the Crimean Mountain Plateaus (Kostenko, I.V. 2014). The content of Fe_{dit} was lower and Fe_{ox} was almost the same as compared to the Umbrisol 1385 profile. To both profiles of Umbrisols, the high level of Exac/Alex was typical *(*see *Table 3).*

Despite the formation under a thick grass stand in similar positions along the relief, the indicators of the humus state of the two soils on the upper plateau of Chatyr-Dag also differed markedly. The profile 1369 of Umbrisol contained almost one and a half times less of SOM and had lower the HR both $Ec^{mg/ml}$ values, which resulted in a less intense colouring of the humus horizon as compared to the Chernic Phaeozem profile 1361 *(*see *Table 4).*

At the northern extremity of the lower Chatyr-Dag a Chernic Phaeozem in the meadow area located inside the forest massif was studied (profile 1306, see *Figure 2*, and *Table 2*). Its profile consists of a dark grey, black in the wet state, very loose horizon Ah and a brown, dense horizon Bt, underlain by the dense limestone. Like the soils of Gurzuf and upper Chatyr-Dag these profiles were strongly differentiated in texture, having argic horizon at the contact with continuous rocks *(see Table 3).* A few years later, the soil cover in these areas was destroyed by wild boars, which dug up the soil to the rock in some places, disrupting the natural sequence of soil horizons.

Chernic Phaeozems of upper and lower Chatyr-Dag, despite the different thermal regime *(see Table 1)*, characterized by close pH, HAc and Exac/Alex values, and slightly differed in BS due to higher bases content in profile 1306. The content of Fe_{dit} in the soil of the plateaus differed insignificantly, and a greater amount of Fe_{ox} was noted in profile 1361 *(see Table 3).*

The TOC content and the total SOM stocks in profile 1306 were lower as compared to the Chernic Phaeozem of the upper plateau. However, the HR and Ecmg/ml values of the profile 1306 were markedly higher, resulting in the Ah horizon colouring intensity close to that of profile 1361 with its much higher TOC content *(see Table 4).*

The Dolgorukov yaila is separated from Chatyr-Dag by the Salgir river valley and is not part of the Crimea Nature Reserve. As a result, its soil cover has been under strong anthropogenic pressure (grazing, mowing, removal of the fertile layer, use as a military training ground, etc.) for a long period. This makes it challenging to choose undisturbed soils, which can occur only in different hollows and sinkholes.

One more example of Crimean Mountain Chernic Phaeozem was described at the slope of hollows (profile 1395, see *Figure* 2, and *Table* 2). This profile consists of a dark gray, black in the wet state Ah horizon, brown with a whitish tint horizon B (Greyzemic), and brown Bt horizon under continuous limestone rock. This profile is different from other soils of mountain meadows by the thickness of more than 1 m and by the whitish plaque on the faces of aggregates in AB horizon.

Compared to the Chernic Phaeozems of Chatyr-Dag, the soil of profile 1395 is characterized by higher pH, lower HAc, Exac/Alex, and higher content of both forms of Fe *(see Table 3).* TOC content and stocks of SOM of profile 1395 were intermediate between profiles 1361 and 1306, HR much higher and $Ec^{mg/ml}$ close to them. According to the RGB values, the intensity of colouration all of the Chernic Phaeozem was very close but greatly different from that of Phaeozem and Umbrisols *(see Table 4).* The latter is confirmed by scattering of R-RGB values in samples of chernic and other horizons of the Mountain Crimea meadow soils *(Figure 3).* According to these data soils with the same TOC content different greatly in R-RGB because of higher HR both $Ec^{mg/ml}$ values of chernic horizons organic matter.

The multiple regression analysis of the data for a large number of samples of Phaeozems and Umbrisols showed that the R-RGB values also were influenced by the content of Fe_{dit}. The content of humic acids carbon (HA) and $Ec^{mg/ml}$ was used for these calculations. The results of calculation for Phaeozems and Umbrisols revealed a high coefficient of determination (R^2 = 0.86; n = 147) and both high correlation for carbon of HA (r = -0.92), $Ec^{mg/ml}$ (r = -0.76) and medium for Fe_{dit} (r = 0.51). For the Chernic Phaeozems obtained similar results for the coefficient of

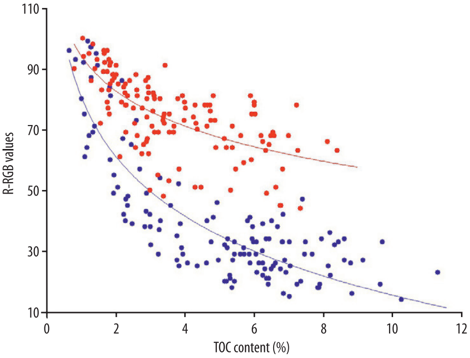

Fig. 3. The influence of TOC content on R-RGB values in soils samples of chernic (blue circles, n = 147), and mollic + umbric (red circles, n = 147) soil horizons

determination ($R^2 = 0.92$; n = 147) both correlation for carbon of HA (r = -0.96), $Ec^{mg/ml}$ (r = -0.75), and very low for Fe_{dit} (r = 0.21). The latter is explained by the influence of dark-coloured OM of chernic horizons, which masks free iron and carbonates, weakening their effect on soil colour.

A comparative analysis of the soils of the mountain meadows of the Crimea and nearby mountain systems revealed both a number of common features and significant differences due, above all, to their confinement to different natural zones. Thus, mountain-meadow soils (Phaeozems, Umbrisols) of the highlands of the Northern Caucasus are formed within the 1,500–3,500 m altitude, which is higher than the maximum elevations of the Crimean plateaus, in conditions of a humid and cool climate with an average annual temperature of -2.9 – +2.3 °C and an amount of precipitation of about 900 mm (Molchanov, E.N. 2010; Volokitin, M.P. 2012). The mountain-meadow chernozem-like soils (Chernic Phaeozems) in the central part of the North Caucasus occur below 1,100–2,000 m (Molchanov, E.N. 2008), in the western Caucasus from 1,200 to 3,100 m, and in the eastern Caucasus from 1,700 to 2,800 m (Fiapshev, B.Kh. 1977; Molchanov, E.N. 2008). Judging by the published data, the mountain-meadow subalpine soils of the Caucasus (Molchanov, E.N. 2010) are close to the Umbrisols of Crimea, confined to the highest plateau positions on Gurzuf yaila (profile 1385) and upper Chatyr-Dag (profile 1369) by values of acidity and composition of exchange bases. At the same time, the Phaeozems of the Crimea differ from similar soils of the Western and Eastern Caucasus (Molchanov, E.N. 2010) by higher acidity and lower BS. The content of TOC in Ah horizons of mountain-meadow subalpine and chernozem-like soils of the Caucasus, according to the available data (Molchanov, E.N. 2008; 2010), is close to its amount in the Phaeozems and Chernic Phaeozems of the Crimean Mountains.

In general, mountain-meadow soils (Umbrisols, Phaeozems) developed on carbonate soil-forming rocks are confined to cool and moist habitats of the alpine and subalpine zones of the Caucasus, while chernozem-like soils (Chernic Phaeozems) are confined to warmer and drier ones (Classification and Diagnosis of Soils of the USSR, 1977; Fiapshev, B.Kh. 1977; Molchanov, E.N. 2008, 2010). Therefore, mountain-meadow soils differ from chernozem-like soils by higher acidity and lower BS. In the Crimea, where the top of yailas does not reach the lower level of the subalpine belt of close latitudes (Grebenshchikov, O.S. 1974), this pattern is broken, as Phaeozems and Umbrisols are formed in the whole range of thermal conditions in the western part of the Main Ridge. Thus, the Phaeozem of the Baydar yaila was formed under warmer and drier conditions compared to the Chernic Phaeozems of Chatyr-Dag and Dolgorukov yailas (see *Table 1).* The latter can be explained by the difference between the eastern and western parts of the Main Ridge in the seasonal distribution of precipitation, as mentioned above.

The feature of the soils of the Crimean mountain meadows is that they are formed in the altitude range corresponding to the forest zone, the upper limit of which at latitudes close to the Crimea is within 1,700–2,300 m a.s.l. (Grebenshchikov, O.S. 1974). So, based on the climatic indicators of the Crimean mountain plateaus, they should be covered with forest vegetation. However, pollen analysis by Artyuschenko, A.T. and Mishnev, V.G. (1978) revealed that there had been no forest belt on the yailas since the Pleistocene. The vegetation in the past, as now, consisted of shrubs and herbaceous plants, and tree species grew mainly in closed depressions where they were not subjected to the adverse effect of strong winds.

In other mountain systems at such heights, Umbrisols and Phaeozems are predominantly formed under forest and shrub vegetation, as evidenced by the data of Costantini, E.A.C. *et al*. (2013b), Giordano, A. (2013), Carballas, T. *et al*. (2016), and Zech, W. *et al*. (2022).

The relief of the Crimean plateaus, with a predominance of gentle slopes and various depressions, is favourable for accumulating loose, non-skeletal weathering products of limestone, whose thickness can reach 1.0–1.5 m or more. Additional moisture influx contributes to the intensive leaching of bases beyond the soil horizons and the formation of neutral soils within the lower altitudes (500–700 m a.s.l.) and strongly acidic soils within the upper (1,300–1,500 m a.s.l.) mountain belt. But as usual, mountain soils contain some amount of skeletal particles and are neutral or slightly alkaline when form on carbonate rocks (Classification and Diagnosis of Soils of the USSR, 1977; Zdruli, P. *et al*. 2010; Carballas, T. *et al*. 2016; Musielok, J. *et al*. 2019).

Conclusions

Fully developed soils of the Crimean mountain plateaus, according to WRB are represented by Phaeozems and Umbrisols with the mollic horizon (mountain-meadow and mountain-meadow dark-coloured soils in classification of 1977 year) and by Chernic Phaeozems (mountain-meadow chernozem-like soils), formed on sialitic weathering crust of dense Upper Jurassic limestone.

The virgin variants of these soils are characterized by similar values of humus content and thickness of the humus horizons but differ in the intensity of their colouration, which is caused by higher values of soil organic matter HR and $Ec^{mg/ml}$ values of Chernic Phaeozems compared to Phaeozems and Umbrisols with mollic horizon. With increasing altitude above sea level, an increase in acidity of mountain soils, characteristic of the vertical-zonal series, was observed.

Phaeozems and Umbrisols are common on Baydar and Ai-Petri plateaus, where they are formed in conditions of the Mediterranean type of precipitation distribution with a maximum in the cold season, and on Gurzuf plateau in conditions of relatively uniform seasonal moisture.

Chernic Phaeozems are found on the lower Chatyr-Dag and on the Dolgorukov yailas, where the maximum precipitation occurs in the warm season, which is also typical for the Chernozems of plains. Upper Chatyr-Dag is a transition zone between the Umbrisols and Chernic Phaeozems, since a combination of both groups of soils characterizes its territory.

The peculiarities of the meadow soils of the Mountain Crimean in comparison to Phaeozems and Umbrisols of mountain systems of nearby mountain systems are that Crimean meadow soils have formed in warmer and drier conditions besides the limits of alpine and subalpine belts on strongly leached non-skeletal fine earth depositions. Virgin Umbrisols and Phaeozems occur only under meadow vegetation, whereas disturbed Phaeozems also are widely distributed under artificial forest plantations.

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