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Soil Genesis

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GENESIS AND PROPERTIES OF RENDZINAS IN THE PODILSKI TOVTRY

Abstract. The geography, physical and physicochemical properties of the Podilski Tovtry rendzinas have been studied. The paper describes the differences in the rendzina ontogenesis caused by lithological, geomorphological, climatic conditions and human activities. The role of the lithological factor in the formation of spatial heterogeneity and the change in the Podilski Tovtry rendzina components have been justified. Differences in physical and physicochemical properties of the studied soil in the natural and man-disturbed state have been established.[1]

The Podilski Tovtry rendzinas are intrazonal, biolithogenic soils formed on eluvial-deluvial sediments of the Neogene limestone and carbonate loess loams. This spatial heterogeneity of the soil forming rocks has caused the formation of the different morphological structure and properties of rendzinas and pararendzinas, which complicates their classification as before neither brown rendzinas nor brown pararendzinas were classified in the Ukrainian soil science. So we have used the works of Polish soil scientists [1–3, 7–9, 13], which have described approaches to the study of the structure and properties of different rendzina subtypes and held their correlation with the world reference base (WRB).

In addition to the spatial changes in the rendzina subtypes caused by lithogenic divergence of the soil forming rocks, unsustainable agricultural development, which leads to the intensification of degradation processes and the formation of agrorendzinas with their specific properties, also has a significant impact on their properties and structure. But due to the low suitability of areas for plow-

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ing, virgin areas and areas with the low impact of anthropogenic activity have been preserved allowing us to investigate and compare rendzina properties in their natural state and under different anthropogenic load.

STUDY AREA

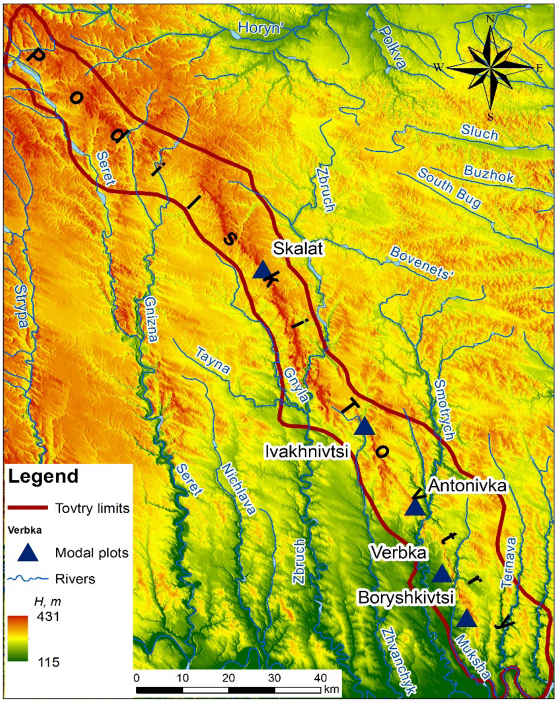

Fig. 1. Location of the study area on the digital map of the Podilya relief

The Podilski Tovtry – the middle Miocene reef formations were formed 13-18 million years ago in the territory of the Podilska Upland in warm coastal waters of the Central Paratethys [11]. In the present relief, Tovtry is represented by the denudation resurrected Baden barrier reef (the main range) and Sarmatian bioherm arrays (lateral Tovtry) with the heights of up to 160 m (Fig. 1.).

The Podilski Tovtry extends in a southeasterly direction from Pidkamin Village in the Lviv Region to the Dniester River, near the city of Kamyanetz-Podilskyi in the Khmelnitsky Region. The length of the Podilski Tovtry is more than 150 km and its width is 5-30 km [11].

In the structure of the soil cover of the Podilski Tovtry, rendzinas occupy more than 17% of the area (Fig. 2).

Most of them are concentrated within Zbarazkiy-Smotrytsky (Tovtry) natural district, the Western Podilska Highland Region [11]. They are confined to flat or slightly convex peaks of the main ridges and peaked rocky peaks of the lateral Tovtry.

Soil forming rocks on the main ridge include lithothamnium limestone and calcareous loess loams on the lateral serpuloid-bryozoans limestone. Lateral ridges are largely treeless covered with meadow steppe phytocoenoses, and within the main ridges treeless areas are interspersed with forests represented by replanted oak-hornbeam formations.

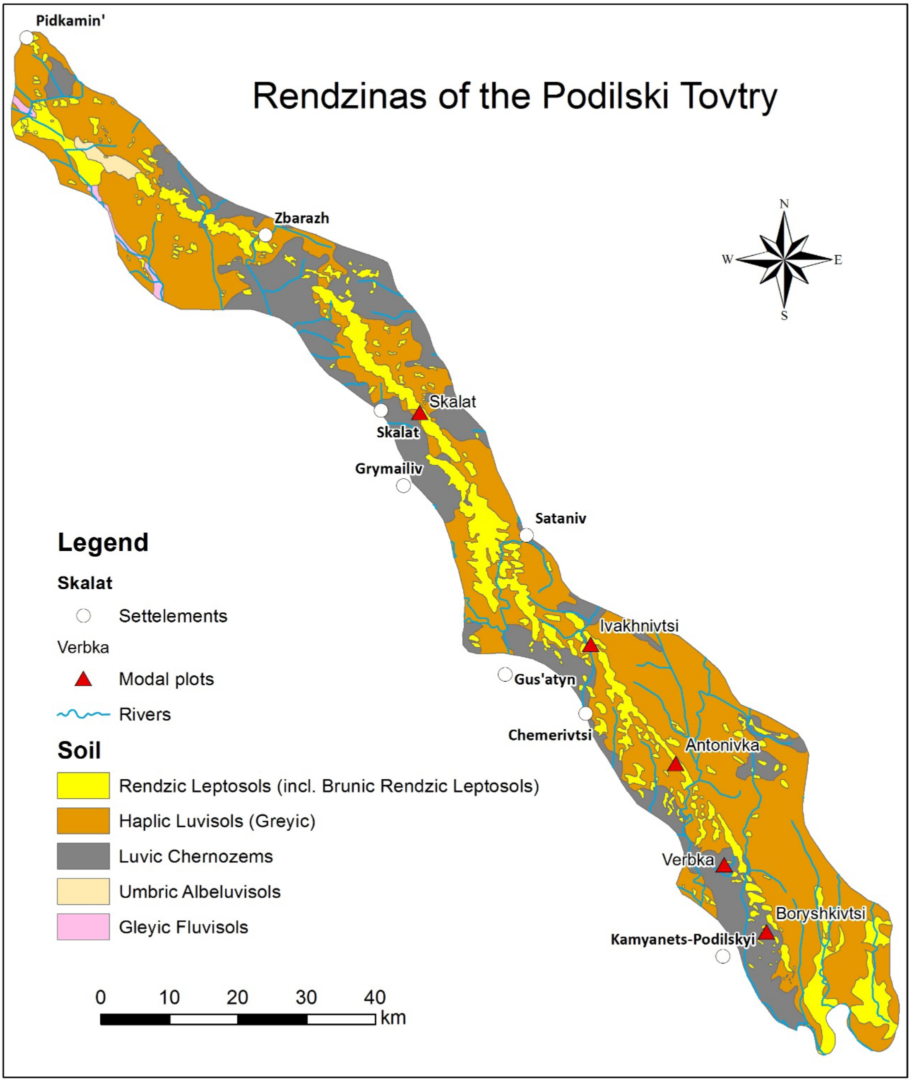

Fig. 2. Rendzinas on the soil map of the Podilski Tovtry

MATERIAL AND METHODS

In 2013-2015 we launched the system of analysed soil profiles in 5 modal plots (Fig. 2) which represent rendzinas on different grounds: arable land, fallow and virgin areas under forest and meadow-steppe phytocoenoses. Soil samples were collected layer by layer (every 10 cm).

To determine the rendzina structure density, the method of cutting ring was used (ring volume – 50 cm^3). The soil water was measured by means of the thermostat-weight method (drying at 105°C).

In the laboratory, the granulometric composition was determined by means of the Casagrande method (ISO 11277:2009), the density of solids – using the picnometer method, C_{org} – by means of the Turin method modified by Nikitin (ISO 14235:1998), pH_{H2O} – using the potentiometer pH 150M (ISO 10390:2005), the content of carbonates – using the calcimeter based on the Heisler-Maksymyuk method (ISO 10693:2010). Calculations and graphical data processing were performed using software packages Microsoft Office Excel 2010 and OriginPro 8.5.1. Cartographic materials were created in the software environment ArcGIS 10.3.

RESULTS AND DISCUSSION

The Podilski Tovtry rendzinas were formed on genetically heterogeneous soil forming rocks causing their different ontogenetic development and properties. Thus, at the peaks of the Tovtry, bedrock Pca (Cca) lies mostly at the depths of 40-75 cm and is presented at the top by rudaceous eluvium of lithothamnium and serpuloid-bryozoans limestone (fragments with the diameter of 80 mm or more), while the lower part is represented by monolithic block formation of greyish-white colour. At the top, due to gaps in rocks, there are a lot of fractures filled with clay pockets of amorphous products of weathering limestone.

On the slopes, in addition to limestone rocks, soil forming rock also includes calcareous loess loams which cover the foot and lower parts of the slopes, with the uneven layer ranging from a few centimeters to several meters. This causes spatial heterogeneity and contrast of the soil cover structure of the Podilski Tovtry. Thus, while at the peaks of the Tovtry – not covered with loess deposits – dark-coloured rendzinas were formed (Rendzic Leptosols), on the slopes, where limestone rocks are gradually overlapping carbonate loess loams, pararendzinas were formed (Brunic Rendzic Leptosol (Calcaric, Skeletic)), which are characterised by a greyish-brown colour (10YR 6/4-7/2), significantly lower C_{org} content in the upper horizon (1.5–2.0%) and clay loam granulometric composition. The increase in the humus profile size is also observed due to the increase in the thickness of the upper HPca (BbrCca) and lower Phca (Cca/Bbr) transitional horizons. In addition, downslope loess loams become the main soil forming rock and cause the development of grey forest soils and black soils (Fig. 3).

Studies have shown that the size of the humus profile of the rendzinas in the territory of the Podilski Tovtry ranges from a few centimeters to 65-80 cm. Its significant part may be found in the humus-accumulative horizon Hca (Aca) with a total capacity of 24–28 cm, which is characterised by distinct dark grey colour (10YR2/14/2 on the Munsell scale), with some whitish limestone spiky fragments of 0.5-2 cm in diameter. Under forest vegetation, in the soil, forest litter is formed to be composed of half-decayed organic residues of 2-4 cm in size,

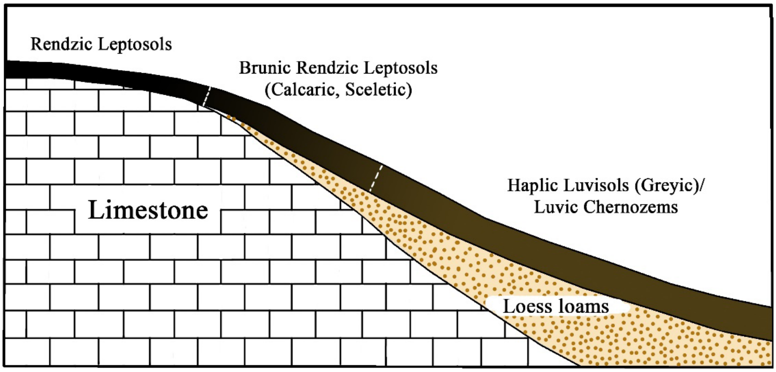

Fig. 3. Scheme of the Podilski Tovtry rendzinas distribution.

below which humus-accumulative horizon with distinct fine-nuciform structure lies. In the upper horizon of the arable rendzinas (agrorendzinas), dusty-fine nuciform structure is observed, and in the subsoil – coarse lumpy structure.

Transition humus horizon HPca (ACca) of whitish-grey colour (10YR 5/1-6/2) of 20-25 cm in size, with the typical fine-lumpy structure, contains a significant amount of debris of lithothamnium and serpuloid-bryozoans limestone, 80% out of which have a diameter of 20 mm. On the main ridge in this horizon, some boulders larger than 10 cm may often be spotted.

Transition horizon to the bedrock Phca (Cca/A) consists up to 70% of the sediments of the bedrock and up to almost 30% of fine soil represented by clay-humus material mixed with amorphous products of lithothamnium limestone weathering. The slopes of the main ridge and the lateral Tovtry are characterised by eluvial-deluvial plume deposits, where reduction in the size of rock fragments and increase in the proportion of clay material are found. The horizon Phca (Cca/A) is of 15-20 cm in size. The fine soil horizon part is structureless.

In terms of the degree of break stone content, the Podilski Tovtry rendzina surfaces belong to surface low cobble (<10%) and surface middle cobble (10-20% of projective cover).

The rendzina grain size analysis (Table 1, Fig. 4) within the modal plots shows significant variability which may indirectly indicate the different stages of soil development. In particular, significant differences in the absolute content of granulometric elements were observed between the dark-coloured rendzinas of the peaks and brown pararendzinas of the Podilski Tovtry slopes. Thus, in the first one sandy fraction of 10.1 mm, the content of which in the upper horizon Hca (Aca) is 35–48%, dominates and decreases down the profile to 12-18% in Phca (Cca/A) horizon, while in pararendzinas its absolute figures in the horizon Hca (Aca) are 3–4% and increase in lower and transitional horizon Phca (Cca/Bbr) to 8-12%. The literature review [10, 12] shows that such sandy fraction distribution is caused primarily by heterogeneous parent rocks.

TABLE 1. PHYSICAL PROPERTIES OF RENDZIC LEPTOSOLS OF THE PODILSKI TOVTRY

Genetic horizon	Depth [cm]	Granulometric composition [%]				Bulk density [g/cm^3]	Particle density [g/cm^3]	Soil porosity [%]	Aeration porosity [%]
		1-0,1 [mm]	0,1-0,02 [mm]	0,02-0,002 [mm]	<0,002 [mm]				
Dark-colored rendzina on eluvium serpuloid-bryozoans limestones, modal plots (MP) «Verbka», profile VC-4 (virgin soil, meadow steppe vegetation)									
Hca (Aca)	3-24	35	41	18	6	0.81	2.29	64.64	49.87
HPca (ACca)	24-41	32	37	22	9	0.93	2.43	61.79	45.19
Phca (Cca/A)	41-58	18	26	42	14	–	2.63	–	–
Pca (Cca)	58-65	–	–	–	–	–	2.76	–	–
Typical rendzina on eluvium lithothamnium limestones, MP «Antonivka», profile AL-1 (forest)									
Hca (Aca)	3-22	3	31	42	24	0.82	2.48	66.90	51.76
HPca (ACca)	22-48	6	30	38	26	1.01	2.58	60.88	43.19
Phca (Cca/A)	48-66	8	25	39	28	–	2.61	–	–
Pca (Cca)	66-71	–	–	–	–	–	2.68	–	–
Typical rendzina on eluvium-deluvium deposits serpuloid-bryozoans limestones, MP «Boryshkivtsi», profile BR-3 (arable)									
$Hca_{(\text{орн})}$ (Aca_{agr})	0-14	10	29	45	16	0.95	2.67	64.34	48.76
$Hca_{(\text{п/орн})}$ (Aca_{agr})	14-27	9	32	52	7	1.34	2.72	50.59	30.12
HPca (ACca)	27-47	12	26	47	15	1.18	2.73	56.84	38.05
Phca (Cca/A)	47-62	14	28	31	27	–	2.75	–	–
Pca (Cca)	62-74	–	–	–	–	–	2.79	–	–
Brown pararendzina on deluvium carbonate loess loams underlay eluvium lithothamnium limestones, MP «Antonivka», profile AP-2 (fallow)									
$Hca_{(\text{орн})}$ (Aca_{agr})	0-10	4	28	46	22	1.26	2.64	51.94	30.08
$Hca_{(\text{п/орн})}$ (Aca_{agr})	10-24	8	19	39	34	1.49	2.70	44.71	22.32
HPca (BbrCca)	24-50	5	23	34	38	1.28	2.73	53.05	31.14
Phca (Cca/Bbr)	50-60	12	21	26	41	–	2.74	–	–
Pca (Cca)	60-70	–	–	–	–	–	2.81	–	–
Dark-colored rendzina on eluvium lithothamnium limestones, MP «Ivakhnivtsi», profile IC-1 (virgin soil, meadow steppe vegetation)									
Hca (Aca)	3-18	48	31	16	5	0.83	2.36	65.43	48.04
HPca (ACca)	18-37	33	36	23	8	0.98	2.52	58.48	39.99
Phca (Cca/A)	37-55	18	27	36	19	–	2.62	–	–
Pca (Cca)	55-65	–	–	–	–	–	2.78	–	–
Typical rendzina on eluvium lithothamnium limestones, MP «Ivahnivtsi», profile IR-2 (arable)									
$Hca_{(\text{орн})}$ ($Aca_{agr)}$)	0-10	22	25	38	15	0.92	2.52	50.92	31.65
$Hca_{(\text{п/орн})}$ (Aca_{agr})	10-22	16	35	41	8	1.34	2.64	46.56	27.72
HPca (ACca)	22-42	12	27	40	21	1.37	2.61	44.75	27.09
Pca (Cca)	42-5	–	–	–	–	–	2.72	–	–

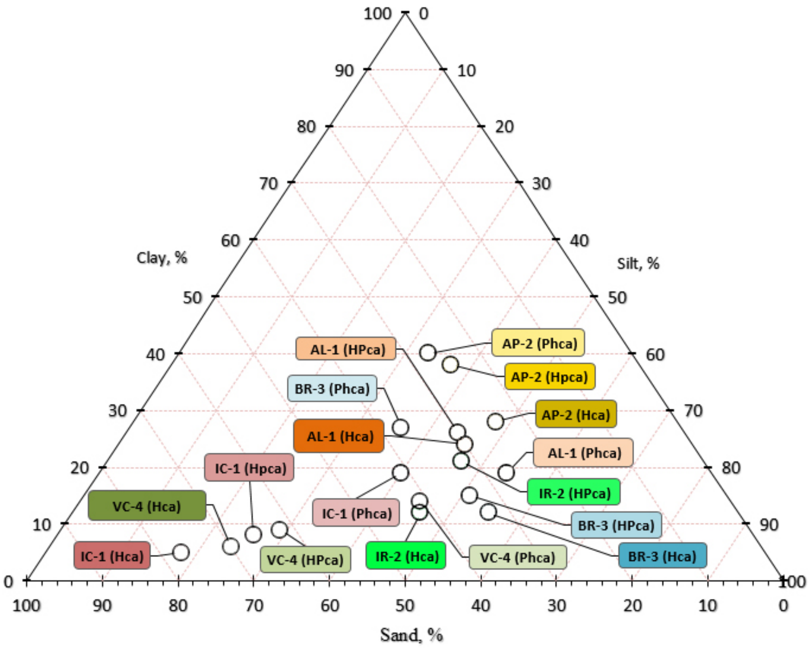

Fig. 4. Granulometric composition of the Podilski Tovtry rendzinas.

Silt fraction <0.002 is characterised by a general increase in its contents down the profile in all rendzina subtypes of the study area. In the upper horizon Hca (Aca) of the brown pararendzinas, its percentage share is 22% and it increases in the transitional horizon Phca (Cca/Bbr) to 40%, while in the dark rendzina it is 5-6% and 14-20%, respectively.

R. Kask found that the rendzina silt fraction distribution pattern, that was referred to, was caused by gradual filling of the lower horizons cavities which occur in soil strata during leaching of solid carbonate elements with alumina particles from the upper horizons [10] and the works of B. Dobzhanskyi et al. [3], noted that the process of decalcification was also important.

The research of the leading soil scientists [1, 5, 12, 13] has proven that long-term agricultural use of rendzina leads to deterioration of its physical and physicochemical properties. In particular, in the genetic agrorendzina profiles we can see a trend of active dissolution process and leaching of solid carbonaceous particles, which reduces the density of soil and redistribution of fine fractions of insoluble residue of original soil forming rocks within the genetic horizons. The structure is destroyed quite rapidly, which leads to the emergence of lumps and consolidation of genetic horizons. As a result, the total porosity and aeration porosity is significantly reduced. The majority of researchers attribute this to the fact that the original properties of virgin rendzinas are favourable for the manifestation of degradation processes [1, 5, 12, 13].

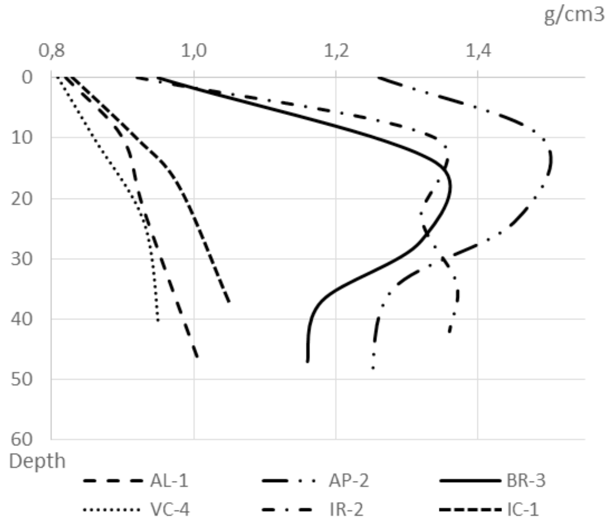

Fig. 5. Bulk density of rendzinas of the Podilski Tovtry.

One of the most dynamic signs of the physical condition of rendzina is the structure density which clearly reflects the level of economic impact on the ground. In particular, the systematic plowing for the same depth has been found to cause the formation of very dense subsoil horizon in the rendzina with a distinct plowing sole structure in its upper part where the density indicators reach values of 1.351.49 g/cm^3, while at the same depth within the virgin areas the figure is less than 1.0 g/cm^3 (Fig. 5).

This is contributed by very loose original structure of rendzina, which on the one hand is a genetic feature of these soils, on the other hand – a favourable condition for deformation [2]. V. Medvedev et al., found that such deformation and compaction under the influence of tillage units extended to a depth of 40-50 cm and deeper. This is confirmed by the results of our studies and proven that in the process of development, rendzina undergoes consolidation within the entire profile due to the small size. The density of the structure of the upper humus horizon Hca (Aca) of virgin and semi-virgin rendzina plots of the Podilski Tovtry is within 0.80.9 g/cm^3, and in the arable and fallow land it reaches the values of 1.201.40 g/cm^3.

In its natural state the Podilski Tovtry rendzinas are characterised by high levels of total porosity and aeration porosity. In the upper humus horizon, total porosity reaches the values of 65-68% and decreases down the profile due to the reduction of total humus, and increases dispersion. The lowest values are reached in plowing sole of arable rendzinas – 4045%.

One of genetically determined rendzina properties is high humus content (Table 2).

TABLE 2. CHEMICAL PROPERTIES OF RENDZIC LEPTOSOLS OF THE PODILSKI TOVTRY

Genetic horizon	Depth [cm]	C_{org} [%]	$CaCO_3$ [%]	pH(H_2O)
Dark-colored rendzina on eluvium serpuloid-bryozoans limestones, MP «Verbka», profile VC-4 (virgin soil, meadow steppe vegetation)				
Hca (Aca)	3–24	8.30	10.75	7.46
HPca (ACca)	24–41	3.92	28.34	7.62
Phca (Cca/A)	41–58	2.08	52.09	7.69
Pca (Cca)	58–65	0.38	56.26	7.70
Typical rendzina on eluvium lithothamnium limestones, MP «Antonivka», profile AL-1 (forest)				
Hca (Aca)	3–22	2.50	0.42	7.22
HPca (ACca)	22–48	1.82	12.50	7.67
Phca (Cca/A)	48–66	0.65	66.26	7.69
Pca (Cca)	66–71	0.15	71.68	7.72
Typical rendzina on eluvium-deluvium deposits serpuloid-bryozoans limestones, MP «Boryshkivtsi», profile BR-3 (arable)				
$Hca_{(орн)}$ (Aca_{agr})	0–14	2.44	10.01	7.52
$Hca_{(п/орн)}$ (Aca_{agr})	14–27	2.27	10.42	7.67
HPca (ACca)	27–47	1.76	18.38	7.68
Phca (Cca/A)	47–62	0.77	27.50	7.70
Pca (Cca)	62–74	0.16	57.51	7.71
Brown pararendzina on deluvium carbonate loess loams underlay eluvium lithothamnium limestones, MP «Antonivka», profile AP-2 (fallow)				
$Hca_{(орн)}$ (Aca_{agr})	0–10	1.58	2.92	7.56
$Hca_{(п/орн)}$ (Aca_{agr})	10–24	1.41	4.58	7.65
HPca (BbrCca)	24–50	1.01	33.34	7.66
Phca (Cca/Bbr)	50–60	0.73	35.84	7.68
Pca (Cca)	60–70	0.09	53.12	7.70
Dark-colored rendzina on eluvium lithothamnium limestones, MP «Ivakhnivtsi», profile IC-1 (virgin soil, meadow steppe vegetation)				
Hca (Aca)	3–18	7.58	2.08	7.54
HPca (ACca)	18–37	3.73	19.17	7.62
Phca (Cca/A)	37–55	1.65	53.34	7.70
Pca (Cca)	55–65	0.13	93.76	7.88
Typical rendzina on eluvium lithothamnium limestones, MP «Ivahnivtsi», profile IR-2 (arable)				
$Hca_{(орн)}$ ($Aca_{agr)}$	0–10	2.58	1.67	7.50
$Hca_{(п/орн)}$ (Aca_{agr})	10–22	2.27	8.75	7.63
HPca (ACca)	22–42	0.63	61.68	7.76
Pca (Cca)	42–55	0.07	89.60	7.85

N. Sibirtsev, who pointed to a key role of $CaCO_3$ in the process of humus formation of the rendzinas, was one of the first scientists to substantiate this feature: excessive amount of $CaCO_3$ and soil solution alkalinity caused by its presence slowed the decomposition of organic matter. In the further clarifications by the scientists, explanation of this phenomenon is as follows: $CaCO_3$ accelerates the decomposition of fresh plant remains, enhances humification processes but helps to perpetuate the humic substances in the soil in a sustainable manner that does not allow further decomposition [12]. Those statements are supported by especially important results of the research by I. Gogolev who in his book [5] pointed out that $CaCO_3$ inhibited the bacterial decomposition of primary humic substances but did not slow down mushroom decomposition, which was often dominant in the forest vegetation.

The above statements are supported by the results of our research. Content of C_{org} in the upper humus rendzinas of the Podilski Tovtry ranges from 1.58% to 8.30% (Fig. 6). It reaches the highest values in small, underdeveloped rendzinas in the peak plots under meadow-steppe vegetation (in some sections over 8.0%) and the smallest value – in pararendzinas (1.5-2.0%).

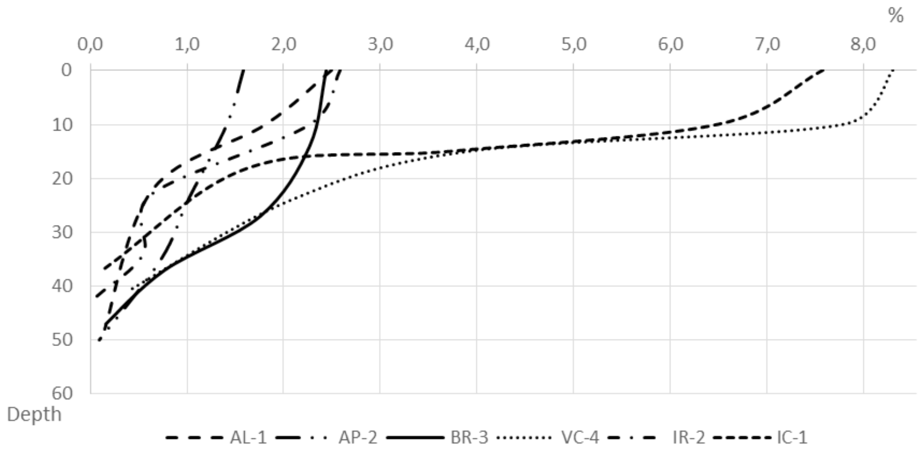

Fig. 6. C_{org} of the Podilski Tovtry rendzinas

Characteristic feature of the Podilski Tovtry rendzinas is the presence of eluvium of the original soil forming rock in the profile as fragments of various sizes and shapes, and finely dispersed carbonate material, which is not morphologically distinct in the fine soil. In the process of intra-soil weathering, dissolution and leaching of carbonates takes place; most of their mass is taken outside the soil profile and partially deposited at certain depth in rock crevices and cavities in the form of occluding structures. These different kinds of carbonates leaching serve as the basis of rendzina ontogenesis and are used as the basis for their classification division of the Russian Soil Science. Within the Podilski Tovtry, intensification of leaching processes occurs under forest vegetation. Overall rendzinas are characterised by illuvial progressive type of carbonate profile. Quantity of carbonates varies from 110% in the upper humus Hca (Aca) to 90% or more in the parent rock. The pH of the rendzina aqueous extract of the Podilski Tovtry varies from slightly alkaline (pH 7.467.56) at the top to alkaline (pH 7.707.72) in the lower horizons.

CONCLUSIONS

1. The Podilski Tovtry rendzinas have some differences due to various lithological, geomorphological, climatic conditions and human activities.

2. Variety of soil forming rocks within the territory causes lithogenic divergence of soil formation largely determining the spatial heterogeneity and dynamic change in rendzina components.

3. Together with the geomorphological and climatic conditions, this leads to the formation of different rendzina subtypes within even one slope under the scheme: dark-coloured/typical rendzina (Rendzic Leptosols) → pararendzinas (Brunic Rendzic Leptosols (Calcaric, Skeletic)), changed by grey forest soils (Haplic Luvisols (Greyic)) or black earth (Luvic Chernozems).

4. Physical and physicochemical properties of the Podilski Tovtry rendzinas undergo significant changes influenced by agricultural use. In particular, due to the agricultural cultivation, the structure is destroyed, genetic horizons become compacted, total porosity and aeration are reduced, C_{org} content is reduced and leaching processes are intensified.

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GENEZA I WŁAŚCIWOŚCI RĘDZIN TOWTR PODOLSKICH

Badano geografię oraz właściwości fizyczne i fizykochemiczne rędzin Tatr Podolskich. Przedstawiono różnice w ontogenezie rędzin, spowodowane litologicznymi, geomorfologicznymi i klimatycznymi warunkami oraz działalnością człowieka. Wyznaczono rolę czynnika litologicznego w tworzeniu przestrzennej różnorodności i zmianie elementów rędzin Tatr Podolskich. Ustalono różnice we właściwościach fizycznych i fizykochemicznych gleb w stanie naturalnym i przekształconych antropogenicznie.