Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development
Vol. 15, Issue 4, 2015
PRINT ISSN 2284-7995, E-ISSN 2285-3952

MORPHOGENESIS OF CARBONATIOUS RENDZINAS PROFILE OF THE WESTERN UKRAINIAN REGION ON DIFFERENT STAGES OF THEIR ONTOGENESIS

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Abstract

The characteristic feature of Rendzinas (Rendzic Leptosols, WRB) is the surface and profile evidence of the residual carbonate inclusions fragmented in different size and form of the initial soil rock, amorphous coarse products of eluviogenesis in the form of farinose carbonaceous dusting and, also, new formations – the fine carbonaceous material, which is not morphologically defined in solid phase of soil. The article justifies the expediency of the macromorphological research parameter usage and carbonaceous admeasurement to identify the character and development direction of the decarbonation processes and the peculiarities of carbonaceous Rendzinas profile morphogenesis on different stages of their ontogenesis.

Key words: *residual carbonate inclusions, amorphous coarse products of eluviogenesis, new formations of the fine carbonaceous material, decarbonation processes, carbonaceous profile morphogenesis, stages of ontogenesis*

INTRODUCTION

Rendzinas (Rendzic Leptosols, WRB) development on carbonaceous soil rocks is mainly defined by the influence of Calcium and Magnesium carbonates. Most of Rendzinas properties depend on the quantity of carbonaceous inclusions, the character of carbonaceous rocks, their mineralogical composition, the quantity and composition of insoluble impurities, peculiarities of weathering [3].

In the process of soil formation on eluvium weathering crust of the massive crystalline or carbonaceous rocks the Rendzinas profile is imposed on the profile of the weathering crust, which is understood as an accumulation of weathering zones that develop under the influence of such physical processes as disintegration, hydration, leaching, oxidation and hydrolysis [4].

It is known that the weathering crust of the carbonaceous rocks has three characteristic layers: fractured, detritus and dispersive. The last layer mentioned is not common everywhere, and only in the shape of separate areas of sand and silty, silty and clay-sand material. The most common combinations seen more often are the detritus and dispersive layers, in which the last one is a filler between the detritus of the carbonaceous rock fragments. Being affected by soil formation, these layers are transformed into genetic Rendzinas horizons, where the processes of weathering and soil formation occur simultaneously. The uniform thickness at the beginning of the hypergenesis process is divided into two dissimilar formations: the soil and the weathering crust or eluvium of the rock [3], [4], [8], [9].

The presence in the genetic profile of petrous soils, broken stone and gravel granulometric elements presented by detritus of initial soil rock, comparatively high content of foreign material of fluvioglacial or eolian origin, consistent water conduction, a large $CaCO_3$ content in solid phase – all this largely reflects the specificity of character and direction of soil forming processes, in particular, the decarbonation and differentiation of carbonaceous Rendzinas profile [10], [11].

In the weathering process of detritus of the soil carbonaceous rocks, dissolution and leaching of carbonates take place, moreover, the main mass goes away from the Rendzinas profile and, partially, is deposited on a specific depth in the fractures and cavities of the rock in the form of occluding formations. It is exposed most clearly in soils with the wash type of water regime in the forest-meadow zone. Thus, Rendzinas are characterized by carbonates only in the form of the deposited formations, and their accumulation in the profile should be reviewed as the intrazonal phenomenon [1], [5], [6], [11].

MATERIALS AND METHODS

The question of carbonaceous Rendzinas profile formation and their decarbonation, as a result of dissolution and leaching of carbonates, is highlighted in many of academic works (Duchafour, 1970; Kask, 1970; Targulyan, 1985; Samoylova, 1986, 1991; Sokolov, 1997; Reyntam, 2001; Zagursky, 2003; Gagarina, 2004, 2012 and others). At the same time, it should be mentioned that the number of academic works dedicated to the problem of differentiation of carbonaceous Rendzinas profile on different stages of their ontogenesis in various natural and natural-anthropogenic conditions of the Western Ukrainian Region is insufficient.

The research carried out by Kask [7] shows that the main process of chemical weathering of carbonaceous rocks is dissolution, in the process of which carbonates are transformed into bicarbonates and are taken out of soils if the water regime is of a wash type (the process of decarbonation). This process is followed by physical weathering, which leads to grinding of tight sedimentary rocks into smaller pieces. According to the data given by the author during 2-3 years, coarse fragments are grinding into 1-5 cm and an average 300-350 kg of $CaCO_3$ are washed away annually from 1 ha area within Estonia. The dissolution of carbonate rocks leads to a residual accumulation of the insoluble residue on the surface. The intensity of such accumulation depends on the composition of carbonate rocks, filtration rate of seeping water, on its aggressiveness and CO_2 concentration in the water. The most intensive accumulation occurs in acidic environment under not very high infiltration water rate and increased CO_2 concentration [7], [12], [14].

Very interesting is Gagarina's publication which shows the mechanism of detritus weathering of carbonate parent rocks [3], [4]. The author notes that in the process of limestone weathering the distruction of structural links occurs due to dissolving, in the first place of cryptocrystalic carbonate substance between carbonate crystals. This increases access of aggressive solutions to carbonates and accelerates their dissolution. As a result, rocks porosity increases, their density decreases and surface roughness enlarges. In neutral conditions carbonate dissolution process slows down and the initial stage of forming weathering product takes place. In case of weathering of the same carbonate rocks in different environments various products are formed. The degree of carbonate rocks conversion depends on their structural and textural features: weathering increases with the decreasing of particles size that make up the rock, the presence of micro and cryptocrystalic calcite mass in intergranular space and increasing of sedimentation links. Since carbonate particles are the least resistant components, they represent a kind of microgeochemical barrier, which deposits substance brought by soil solution, resulting in claying and ironing of carbonate particles [3], [4], [15]. As a result of dissolution carbonate rocks change their appearance: colour changes (brown colour appears), volume decreases and porosity increases. Accordingly, chemical and mineralogic composition of carbonate particles changes.

The aim of this work is to substantiate advisable macromorphologic research parameters and carbonation values in order to establish the nature and direction of decarbonation processes development and peculiarities of carbonate Rendzinas profile morphogenesis on different stages of their ontogenesis and in different natural and natural-anthropogenic conditions of the Western region of Ukraine.

For the analysis of morphogenesis

peculiarities of carbonaceous Rendzinas profile on different stages of their ontogenesis we used comparative-geographical, morphologo-genetical and cartographical methods.

Expedition and semi stationary methods were used in field investigations.

Analytical work was performed according to standard procedures, CO_2 carbonates - according to the method of Gejsler-Maksymjuk, bulk density - by the method of cutting the ring (size 50 cm^3) from the laboratory of Lytvinov, carbonate stocks and differentiation factor of carbonate content - by the calculation method.

RESULTS AND DISCUSSIONS

According to physical-geographical zoning (Marynych et al., 2003) Western region of Ukraine is located within the two countries: East European Plain and the Ukrainian Carpathians. The research comprises the mixed forests zone of Polisya, where two regions of Volynian and Maly Polisya are differentiated, and also the zone of broadleaf forests of the Western Ukraine, which is divided into five regions: Volyn', Western-Podil's'k, Central Podil's'k, Prut-Dnistrovs'k heights and Rostots'k-Opils'k region (Roztochia and Opilya) [13].

The climate of the research territory is characterized as moderately continental, with long hot summers, short mild winters and adequate moisture. The average annual precipitation – 600–700 mm. Hydrothermal coefficient is 1.43–1.74. Currently, the natural vegetation (mixed and deciduous forests with well-developed grass cover) under which the studied soils were formed is almost entirely transformed by human activity. Arable lands dominate in the structure of agricultural land. The plow - 79.5% [17].

During 2003–2013 eleven modal plots were laid, which represent the chronological rows of Rendzinas that correspond to different space-time stages of their ontogenesis and are formed on the products of eluviogenesis of different carbonate rocks. Every modal plot is represented by 10 supporting soil profiles (Fig. 1).

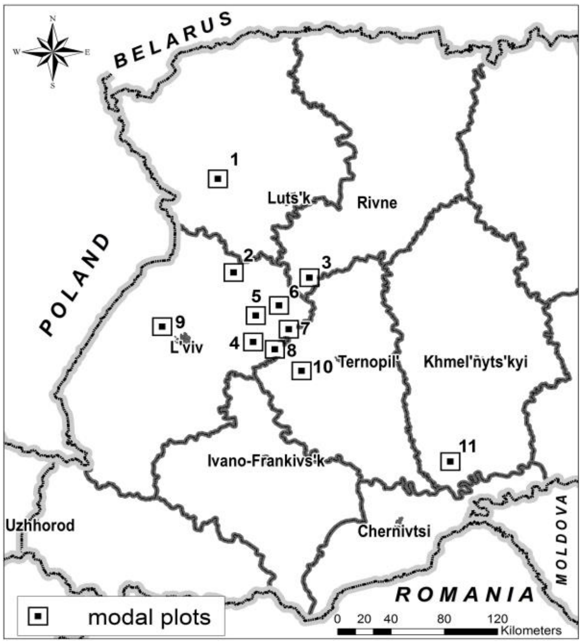

Fig. 1. The research territory
Source: Author's map

Elements of chronological rows which were studied, were not separate soils, but the collection of Rendzinas varieties which according to the profile capacity are divided into: poorly-developed (< 25 cm), short-profiled (from 25 to 45 cm), fully-profiled (> 45 cm) which are confined to different relief elements (denudation undulating plains, upland interfluves, plain-tuberous and hilly-upland areas, remnants of limestone hills, steep (> 10^0) and very declivous slopes of rivers, etc.), types of parent rock (eluvium of Turon-Senon chalk and chalk-marl deposits, eluvial-diluvial Turon-Senon chalk marl deposits, eluvium cluster, chemogenic and lithothamnium limestones of upper Badenian) and vegetation (associations of perennial grasses, pine woodlands, beech and pine forest, associations of perennial grasses with moss impurities, zonal cultural vegetation, and without vegetation), that is, chronological rows can be defined as pedotopocatens, pedolithocombinations and pedophitocombinations [12], [17].

The predominant parent rocks within Volynian Polisya, Maly Polisya and north-western part of West-Podilsk highland region are the products of eluviogenesis of Turon-Senon deposits of the upper cretaceous system, lithologically represented by chalk and chalk marl. At the same time within

Roztochya-Opilsk highland region and the central part of Western Podilsk highland region the predominant parent rocks are products of eluviogenesis of upper Badenian deposits lithologically represented by cluster, chemogenic and lithothamnium limestones. $CaCO_3$ content in presented rocks changes in a wide range. The highest $CaCO_3$ content is present in the products of eluviogenesis of chalk which makes from 75 to 98%. $CaCO_3$ content in the products of eluviogenesis of chalk marl is also quite high, ranging from 40 to 95%. Somewhat lower $CaCO_3$ content presented in the products of eluviogenesis of cluster, chemogenic and lithothamnium limestones, in which it varies from 54 to 92%.

Rendzinas formation on the products of eluviogenesis of carbonate parent rocks causes significant $CaCO_3$ content in the soil profile. Almost all investigated soils are medium and strongly carbonate on the surface and within the profile. According to Gogolev [6] $CaCO_3$ content in humus accumulative Rendzinas horizon in Western region of Ukraine ranges from several to several tens of percent, preferably 30-40%.

A characteristic feature of Rendzinas is the presence of eluvium of original parent rock as fragments of various size and shape in the profile, as well as finely dispersed carbonate material which is not morphologically identified in the solid phase [9], [10], [11].

The basis of Rendzinas evolution is a gradual leaching of $CaCO_3$ rocks. According to Kask's investigations such characteristic features of carbonate leaching process from soil have been highlighted [7]:

- reducing of quantity and the size of initial carbonate rock fragments and carbonation of solid phase in the upper horizons;
- corrosion of carbonate particles surface;
- appearance of yellow-brown iron hydroxide covering on the surface of carbonate particles;
- decreasing of fragments strength in carbonate rocks;
- appearance of silicate particles carbonate crusts and covering on the bezel surface, which were formed due to precipitation of secondary carbonates from $Ca(HCO_3)_2$ solution by evaporation of the latter;
- appearance of terrigenous material dusting powder on the surface of carbonate broken stone.

In the classification the stages of this process define the subtypes of Rendzinas, where one of the main diagnostic features is the presence of morphologically expressed or unexpressed carbonate accumulations, in some form or other, at a certain depth which is detected by 10% HCl. Typical Rendzinas react on the surface under the influence of 10% HCl, leached only at the bottom of the profile, ashed (according to new terminology lessivage), have signs of colloids redistribution in the profile and react only within the parent rock [8].

Significant content of carbonates within the whole profile determines the formation of many important soil properties: porosity, soil connectivity, bulk density, structure, fractional humus composition, composition and concentration of soil solution. Carbonates play an extremely important role in alkalinity soil formation. Moderate $CaCO_3$ content promotes the formation of well-defined structure, provides stable buffering, causes close to neutral (or weakly alkaline) reaction of soil solution. High level of carbonate accumulation usually degrades physical and physical-chemical soils properties [14].

To study the features of carbonate Rendzinas profile formation chronological rows which are associated with the presence of various carbonate forms, and identification of possible changes in distribution and forms of their manifestation within perfect and permanent stages of their ontogenesis (depending on developed profile), detailed macromorphological studies and determination of $CaCO_3$ content and stocks have been conducted (Table 1).

For Rendzinas on the investigated territory carbonates are mainly in the forms of residual formations. The residual carbonates are:

- carbonate inclusions in the forms of fragments of various size and shape of the initial parent rocks;
- amorphous solid phase coarse and finely dispersed weathering products in the form of powdered carbonate dusting and carbonate residual neoplasms (whitish-grey or whitish-brown "saturated" halos around detritus of the

original carbonate rocks) and also not morphologically expressed in solid phase as carbonate impregnation.

Carbonate content in the investigated soil profile naturally varies with depth, forming several specific strips (zones) of prevailing forms of residual carbonate formations, indicating carbonate differentiation of their profile. Based on macromorphological studies of soil sections three strips are selected.

The *first strip* – from the soil surface to a depth of 25-30 cm with the presence of a small amount of carbonate parent rock fragments, 80-90% of which having diameter from 20 to 7 mm; 20-10% for pieces with a diameter less than 7 mm. It has been stated that the number of visible carbonate parent rock fragments (d=20-7 mm) in the column of 10 cm wide within this strip varies from 16 to 23 units. Carbonate inclusions undergo severe weathering and mechanical destruction (in cultivated variants), testifying modified close to the oval shape, slight bulk density and the formation on their surface of friable weathered layer with the thickness of about 2-3 mm. In addition, the presence of finely dispersed solid carbonate material is observed in the form of powdered dusting on bezels of structural units, on the walls of root passages and mesofauna. The presence of residual carbonate neoplasms in the form not expressed morphologically (carbonate impregnation) is permitted, which indirectly indicates rapid and continuous reaction of 10% HCl with total solid phase.

The strip is characterized mainly by low $CaCO_3$ content and its significant variability (4.48 – 41.0%). This indicates the trend of dissolution process development and carbonate leaching (Table 1).

The *second strip* – at the depth of 30 to 45 (50) cm. There is visible in the upper part and quite significant in the lower part increase of size and content of carbonate parent rock fragments, 70-80% of which are over 20 mm, 30-20% from 20 to 7 mm or less; the column of 10 cm within the strip contains from 17 to 24 units of carbonate visible inclusions, which due to larger size take a significant strip capacity.

Table 1. Carbonate content and stocks in Rendzinas and differentiation factor of their profile

Horizon	Depth, cm	Db^a, Mg/m^3	$CaCO_3^b$, %	S_{CaCO3}^c, t/ha	Sk^d
Fully-profiled Rendzinas MP[e] №1, "Kupychyv"					
Ap_{Ca}	0-16	1.34	17.98	240.93	4.38
ACp_{Ca}	16-32	1.48	16.34	241.83	
A/C_{Ca}	32-42	1.36	77.63	1055.77	
C_{Ca}	52-62	-	82.54	-	
Fully-profiled Rendzinas MP №2, "Radekhiv"					
$Ap1_{Ca}$	0-22	1.50	23.05	345.75	2.45
$Ap2_{Ca}$	23-33	1.48	25.83	382.28	
AC_{Ca}	35-45	1.43	45.15	645.65	
A/C_{Ca}	50-60	1.30	65.10	846.30	
C_{Ca}	65-75	-	81.30	-	
Short-profiled Rendzinas MP №3, "Radyvyliv"					
Ap_{Ca}	0-10	1.37	9.24	126.59	1.22
ACp_{Ca}	21-30	1.52	10.16	154.43	
C_{Ca}	30-40	-	90.82	-	
Fully-profiled Rendzinas MP №4, "Bilyj Kamin"					
$Ap1_{Ca}$	0-25	1.52	12.35	187.72	2.86
$Ap2_{Ca}$	25-31	1.57	13.50	211.95	
AC_{Ca}	32-45	1.53	28.51	436.20	
A/C_{Ca}	55-65	1.45	37.00	536.50	
C_{Ca}	70-75	-	78.90	-	
Fully-profiled Rendzinas MP №5, "Khvativ"					
$Ap1_{Ca}$	0-17	1.23	12.26	126.28	3.26
$Ap2_{Ca}$	17-30	1.38	13.08	180.50	
AC_{Ca}	32-42	1.42	28.60	406.12	
A/C_{Ca}	42-52	1.36	30.24	411.26	
C_{Ca}	65-75	-	40.04	-	
Anthropogenically-violated Rendzinas MP №6, "Jaseniv"					
Ap_{Ca}	2-30	1.23	12.67	155.84	2.91
ACp_{Ca}	30-49	1.36	15.53	211.21	
Ab_{Ca}	49-58	1.35	13.89	187.52	2.42
ACb_{Ca}	58-68	1.27	29.42	373.63	
A/Cb_{Ca}	73-83	1.48	30.65	453.62	
C_{Ca}	90-100	-	40.08	-	
Poorly-developed Rendzinas MP №7, "Bila Hora"					
AC_{Ca}	0-13	1.01	27.62	278.96	1.76
A/C_{Ca}	13-20	1.31	37.55	491.90	
C_{Ca}	40-50	-	47.82	-	
Fully-profiled Rendzinas MP №8, "Voronjaky"					
Ap_{Ca}	0-20	1.35	31.65	427.28	1.85
AC_{Ca}	30-40	1.45	41.00	448.63	
A/C_{Ca}	42-52	1.32	59.80	789.36	
C_{Ca}	60-70	-	92.51	-	
Short-profiled medium leached Rendzinas MP №9, "Ivano-Frankove"					
A_{Ca}	4-21	1.02	-	0	-
A/C_{Ca}	35-45	1.32	31.14	411.05	
C_{Ca}	65-75	-	92.85	-	
Fully-profiled Rendzinas MP №9, "Ivano-Frankove"					
A_{Ca}	3-19	1.01	4.48	45.25	15.22
AC_{Ca}	19-32	1.19	32.28	384.13	
A/C_{Ca}	42-52	1.36	50.64	688.70	
C_{Ca}	65-75	-	92.85	-	
Fully-profiled Rendzinas MP №10, "Bererzany"					
$Ap1_{Ca}$	0-17	1.12	19.59	219.41	2.42
$Ap2_{Ca}$	17-34	1.36	23.68	547.48	
AC_{Ca}	41-51	1.30	29.12	378.56	
A/C_{Ca}	55-65	1.38	38.55	531.99	
C_{Ca}	85-95	-	54.11	-	
Fully-profiled Rendzinas MP №11, "Boryshkivtsi"					
$Ap1_{Ca}$+ $Ap2_{Ca}$	0-27	0.95	10.21	97.00	3.97
AC_{Ca}	27-47	1.34	20.76	278.18	
A/C_{Ca}	47-62	1.40	27.50	385.00	
C_{Ca}	65-75	-	57.50	-	

Note. a – average values of bulk density, Mg/m^3 (n=5); b – average values of $CaCO_3$ content, % (n=10); c – carbonate stocks, t/ha; d - differentiation factor of carbonate content; e – modal plot.
Source: Own calculation

A characteristic feature of this strip is the formation of “saturated halo” around carbonate inclusions in the form of coarse carbonate amorphous mass of whitish-grey or whitish-brown colour, about 3-4 mm thick, being the result of intensifying process of carbonate dissolution and leaching under the influence of favorable hydrothermal conditions and fulvic acid (FA-1a) fraction, the content of which is significantly growing within the strip. Along with carbonate inclusions the presence of morphologically expressed coarse carbonate material occurs in solid phase, testified by a whitish hue. Considerable number of inclusions in the form of amorphous products of eluvium weathering occurs, to a lesser extent, due to weathering of carbonate parent rock fragments “in situ” and to a bigger extent – due to migration of salts in the form of carbonate $Ca(HCO_3)_2$ from the upper strip and their precipitation, as a result of $CaCO_3$ excess. As Samoylova [15] and coauthors state, after dissolution and removal of free carbonates from the top of the profile, the carbonates of deeper horizons almost do not dissolve, as solutions coming from the top are saturated by bicarbonate and cannot dissolve them. $CaCO_3$ content compared with the upper strip increases significantly and is 20.70−72.69% (Table 1).

Samoylova and Tolchelnikov [16] believe that capacity growth of Rendzinas genetic horizons (hence the second strip capacity) is in direct proportion to the capacity growth of alkali thickness.

The *third strip* – lies at the depth of 45 (50) to 60 (65) cm, sometimes deeper, composed mainly by coarse fragmental carbonate material; detritus size ranges from 30 to 50-70 mm. This carbonate material is surrounded by clay-humus mass, which is marked by uneven greyish-white colour, sometimes with a brownish hue, due to uneven mixing with weathering products of the initial parent rock, as stones, gravel, sand and dust. Carbonate coarse detritus is characterized by a quite significant density (hardly destroyed), square shaped with a relatively well-defined clear bezel. On the surface of inclusions traces of initial dissolution in the form of greyish-white powder dusting not more than 1-2 mm thick can be seen. $CaCO_3$ content is somewhat lower than in the parent rock and ranges from 27.50 to 77.63% (Table 1).

The feature of profile carbonate content distribution in Rendzinas is their quite gradual growth in the upper part of soil profile to a depth of 10-20 cm in underdeveloped and low profiled and 20-40 cm complete profiled and also rapid growth of their content in lower and middle parts. Distribution curve has a clear concave shape, indicating almost uniform removal of carbonates under the influence of dissolution and leaching. According to the classification by Kovda and Rozanov [8] soils under study are characterized by regressive-eluvia type of the profile carbonates content distribution, approaching to uniformly eluvia in some cases.

Morphologically expressed differentiation of visible carbonate formations and inclusions in Rendzinas (Rendzic Leptosols, WRB) profile are combined with the gradual growth of their content down the profile. On this basis poorly-developed Rendzinas relate to strongly differentiated (Sk=1,76), short-profiled to weak and medium differentiated (Sk=1.22 – 1.44) and fully-profiled mainly to sharply differentiated (Sk=2.11−15.22). Fully-profiled Rendzinas (MP №9, “Ivano-Frankove”) which were formed on the eluvium cluster limestones of upper Badenian, under beech and pine forest with developed grass cover have the highest carbonate profile differentiation (Sk=15.22) (Table 1).

For complex assessment of carbonation variability in Rendzinas you have to take into consideration that the bulk density of genetic structure in different soil horizons is different. Therefore, carbonate content data have been listed in their stocks (t/ha) for each genetic horizon of soils under study and separately for a layer 0-20 cm (Table 1).

Comparative analysis of indexes of carbonates content and stocks in Rendzinas of defined chronological rows enables to note the following:

- the largest carbonate reserves in 0-20 cm layer are in poorly-developed Rendzinas which were formed on the eluvium of Turon-Senon chalk-marl deposits are on the modal

plot №7 “Bila Hora” (770.86 t/ha) (Table 1);
- the least carbonate reserves in 0-20 cm layer are in fully-profiled Rendzinas which were formed on the eluvium cluster limestones of upper Badenian are on the modal plot №9 “Ivano-Frankove” (45.25 t/ha);
- carbonates in short-profiled medium leaching Rendzinas of modal plot №9 “Ivano-Frankove” in 0-20 cm layer are completely absent. This is primarily due to the fact that the soils are under forest. As Duchafour [2] states, in similar soil forming conditions the process of carbonate leaching under the forest is 4 times faster than under meadow and steppe vegetation;
- in case of transition of poorly-developed Rendzinas into short-profiled (modal plot №7 “Bila Hora”) carbonate reserves in the latter slightly increase due to higher bulk density of upper horizons of short-profiled Rendzinas;
- in case of transition of short-profiled Rendzinas into fully-profiled, carbonate reserves in their profile increase;
- carbonates content and stocks in fully-profiled Rendzinas increase almost uniformly down the profile to a parent rock (modal plots №1, 2, 4, 5, 8, 9-11) (Table 1);
- carbonates content and stocks in anthropogenically-violated Rendzinas (modal plot №6, “Jaseniv”) change unevenly down the profile to a parent rock (Table 1).

CONCLUSIONS

Analysis of macromorphological and laboratory-analytical research data indicates certain morphogenesis features of carbonaceous Rendzinas (Rendzic Leptosols, WRB) profile on different stages of their ontogenesis. It has been discovered that the formation of investigated Rendzinas carbonate profile, the present state of which corresponds to perfect and permanent stages of ontogenesis in different natural and natural-anthropogenic conditions of Western region Ukraine is characterized by a predominance of carbonates in the form of residual formations, domination of decarbonation processes, the intensity of which increases in accordance with the above stages and the degree of differentiation of their profile from low and medium to sharply differentiated.

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