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THE INFLUENCE OF THE SLOPE EXPOSURE ON THE SOIL AGGREGATION AND STRUCTURE, WATER STABILITY OF AGGREGATES, AND ECOLOGICAL MICROSTRUCTURE FORMATION OF THE RAVINE FOREST SOILS IN PRE-DNIPRO REGION (UKRAINE)

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Abstract

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The soil aggregation and structure, water stability of aggregates, and peculiarities of microstructure formation of the ravine forest soils in Dnipropetrovsk region on the example of the northern variant of the ravine forest "Kapitanivskiy" have been identified. The soil properties of southern and northern ravine exposures have been compared. The soil structure, aggregate composition, water stability of aggregates as well as soil-forming processes of the ravine ecosystem have been analyzed. Micromorphological studies have shown a high degree of aggregation of the upper (0–60 cm) horizons of the soil profile. The structure-forming process is of a zoogenic origin. Aggregates of coprolite nature contain well-disintegrated plant remains. Dark gray, almost black color along the entire area of the micromorphological slide is due to a large amount of organic compounds, which indicates active processes of humification. Fine-dispersed humus consists of a large number of evenly spaced humus clusters. The type of humus is mull. The skeleton consists of minerals of various sizes, dominated by quartz and feldspars. Plasma is humus-clay, homogeneous throughout the entire slide, anisotropic with speckled glowing. Microstructure is mainly aggregated and, in some places, spongy, depending on a microzone of the soil slide. Elemental microstructure is of plasma-silty type. The area of the visible surface of the pores in the upper horizons of the soil profile is fairly large (40%). Pores are round and elongated, of regular shape, here and there with remains of small invertebrates. The deeper the soil slide is, the smaller the area of visible pores along with aggregation becomes. Correlating with micromorphological characteristics, water resistance of structural aggregates reaches very high (90.01% ± 3.07) values in the upper horizons of the soil slide, decreasing at depths. The coefficient of pedality is rather high (7.83 ± 0.81) in the upper horizons, decreasing at depths.

Key words: ravine forest, soil, structure, aggregation, water resistance, micromorphology.

Introduction

Forests are of paramount importance for improvement of the ecological situation of Ukraine. Multifunctional properties of forests contribute to a significant increase in soil fertility by means of transforming the surface water flow into the deep one. Preventing from the destructive influence of dry winds, forests hinder soil erosion (Bilova, 1997). The conclusions of the Spanish and French scientists, who regard phytostabilization as the most successful solution to the chemical, toxicological, and environmental problems related to soil contamination (Epelde et al., 2014; Nsanganwimana, 2014), coincide with our ideas.

In the ecological network of Ukrainian forests, ravine forests are of great importance. Throughout the steppe area, there are a number of locations of a significant topographic low (ravines) covered by wild ravine forests, which are situated in their natural environment. The absence of molehill, as opposed to steppe biogeocoenosis, the presence of the traces of old roots of dead trees, the well-formed specific sedentary-illuvial soil profile and others testify the early occurrence of ravine forests in the steppe (Bilova, 1997; Bilova, Travleev, 1999).

Ravine forests are of great scientific value to study the peculiarities of the formation of natural forests, where rare and endangered species of plants and animals have found shelter. In addition, ravine forests can set an example for growing anti-erosion plants as well as become a treasury of the seeds of wood and shrub breeds.

Soil is the main, resultant forest ecosystem unit. It is impossible to maintain and restore ravine forests without a thorough study of soil characteristics.

The properties of soils are studied by scientists from all over the world. Spanish scientists research the influence of the abiotic factors (temperature, soil moisture, and ultraviolet irradiance ratio) on the soil ecosystem (Morgado et al., 2015), the impact of long-term use of chemical and organic fertilizers on a large number of nitrogen-containing microbial communities of soil (Sun et al., 2015). Brazilian scientists investigate the role of earthworms in soil formation (Zúñiga et al., 2013), the effect of worms on quality characteristics of soils (Bartz et al., 2013). Iranian scientists conduct researches connected with the influence of the climate humidity grade during soil-forming processes of loess soils (Khormali et al., 2012), micromorphological aspects of the development of forest soils evolved from eruptive rocks in Lahidzhany (Ramezanpour, Pormasoumi, 2012) influence of technogenic disturbances on understory of oak forests (Eshaghi et al., 2017). German scientists investigate the relationship between macropores of the soil and its hydrological properties (Bogner et al., 2014). Slovak scientists carry out a number of substantial studies connected with the characteristics of physical properties of soil profiles under introduced trees (Polláková et al., 2017), development of a soil water regime (Tužinský et al., 2017), determination of Organic Fractions and Enzymatic Activity in Forest Spruce Soil of Tatra National Park (Gáfriková et al., 2018), dependence of the soil reaction on the number of mites (Buza, Divos, 2016), fluctuations of nutrients in the upper soil horizons under the bedding of different wood species (Polláková et al., 2015), assessment of the organic substance of soils from different ecosystems in relation to the carbon parameters (Tobiašová et al., 2015), and the Contingency of Soil Microorganisms and the Selected Soil Biotic and Abiotic Parameters Under Different Land-Uses (Júdová et al., 2019).

Ukrainian scientists comprehensively and thoroughly investigate the properties of soils, in particular, the selective absorption of heavy metals by soil and humic acids at different pH levels (Miroshnychenko, Kutz, 2016), the coloristic criteria of the S-matrix of brownish ashy gleyed soils of the Pre-Carpathian region (Nikorych, Chervonogrodska, 2016), the issues of diagnostics of elemental soil processes and profile-differentiated soils in the Pre-Carpathian region (Smaga, 2016), and the ecological and evolutionary analysis of the content of lithium in soils (Dmytruk, 2016). They also predict the content of chemical elements in soils of different genesis for assessing the ecological and energy status (Samokhvalova et al., 2016), study soil features of floodplain soils that limit the growth of energy crops (Kholodna, 2016), and assess the antideflationary efficiency of the "No-till" technology in the conditions of the southern steppe of Ukraine (Chornyy, Volosheniuk, 2016). We fully agree with the ideas of Prof. Medvedev, who believes that one of the most important tasks of the state is monitoring of soil cover on the basis of the latest software, mathematical, instrumental, and cartographic principles in compliance with the European experience (Medvedev, 2016).

Scientists of Dnipropetrovsk school of soil have been studying soil properties, the nature of soil formation, and the genesis of soils in the southeast of Ukraine (Belgard, 1950, 1971; Bilova, Travleev, 1999). The monitoring of the influence of a mole rat's digging activity on the restoration of proteolytic activity of soils under conditions of their technogenic contamination (Zamesova, 2016), the presence of heavy metals in the subsoil waters of Prisamarja Dniprovskogo (Kotovych, 2016), the dielectric penetration of the ravine soils (Gorban, 2016), the macro- and micromorphological differentiation of the humus-accumulative horizons of forest soils (Yakovenko, 2016), the effect of soil on spatial variation of the herbaceous layer modulated by overstorey in an eastern European poplar-willow forest (Zhukov et al., 2019) as well as the long-term monitoring of land recultivation (Zverkovsky, Zubkova, 2016), the features of the structural and aggregate composition of black soil in ravine forests (Gorban et al., 2016), and lithologic heterogeneity of the profile of ravine soils (Yakovenko, 2017) is being conducted.

The ravine forests of southeastern Ukraine are of great interest for scientific researchers-ecologists. In ravine forests, there are soils characterized by unique ecological, in particular, microclimatic features of soil-forming processes. The purpose of this study is to specify the structural and aggregate composition, water resistance of aggregates and microstructure formation of soils of the southern exposure of the ravine as well as to compare the study results with the soil properties of the northern exposure of the research object, which we studied earlier (Bozhko, Bilova, 2010).

Material and methods

Natural ravine forests of the northern variant of Dnipropetrovsk region emerged on the plateau located on the right bank of the Dnipro River. As an example of such ecosystems, we have chosen "Kapitanivskiy" ravine situated at 48°46.1502'N, 35 °37.3164'E (Fig. 1).

The methodological approach of our research is based on the typological principles developed by A. L. Belgard (Belgard, 1971) for steppe forests as well as the methodological principles of ecological micromorphology of soils proposed by N. A. Bilova and A. P. Travleev (Bilova, Travleev, 1997). Both field studies, geobotanical description and bioecological characteristics of flora are based on generally accepted methods and approaches. The micromorphological structure of soils has been studied in accordance with the methods developed by O. I. Parfyonova and K. A. Yarilova (Parfyonova, Yarilova, 1977), S. A. Shoba (Shoba, 1981). Transparent slides have been made in accordance with E. F. Mochalova's method (Mochalova, 1956), "Methodological manual on micro-morphology of soils" edited by G. V. Dobrovolsky (Dobrovolsky, 1983) has been used during decryption; identification of aggregate composition has been carried out by dry sifting of soil samples through a sieve with each soil profile divided into 10 zones, 10 cm each, and soil samples have been taken from top to bottom along the cut; the coefficient of soil structure $K = C/B$

Fig. 1. Location of the researched object: "Kapitanivskiy" ravine (1).

has been determined in accordance with I. B. Revut's method (Revut, 1964; Nweke, Nnabude, 2014), where *C* is the number of structural separates of 0.25–8.00 mm, *B* is the sum of separates larger than 8.00 mm, and silty separates smaller than 0.25 mm; analyses of water resistance of structural aggregates have been carried out in compliance with M. E. Bekarevich's and M. V. Krechun's method (Bekarevich, Krechun, 1964; Molina et al., 2001); the average square deviation was determined by formula:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{N-1}} \quad ;$$

the coefficient of indicators correlation was determined by formula:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \times \sum(y_i - \bar{y})^2}} \quad .$$

Results

The sample area under study is laid in the middle third of the slope at 20° of the southern exposure. Humidifying is atmospheric-transit, inflowing-outflowing. Microrelief is wavy. The type of forest biogeocoenosis is a fresh ash-tree and maple wood. The timber stand consists of 40% *Fraxinus excelsior* L., 30% *Acer compestre* L., and 30% *Quercus robur* L. Light structure is half-shade. Crown density is 0.7. The total coverage of the grass stand is 50%. Bioecological certification of the grass stand is presented in Table 1.

T a b l e 1. Bioecological certification of the ravine grass stand.

№	Plantname	Layer	Height (cm)	Vegetation stage	Abundance according to Drude	Coverage (%)	Vitality points
1	*Pulmonaria obscura* Dumort	H_2	16	v, ~	Cop_1(gr)	2	4–5
2	*Scutellaria altissima* L.	H_1	45	#, ~	Sp	2	4
3	*Stella riaholostea* L.	H_2	12	–	Cop_1(gr)	3	4
4	*Viola odorata* L.	H_3	5	–,	Sp	2	3–4
5	*Chaerophyllum temulum* L.	H_3	5	v, +	Sp	1	4

Notes: Layer: H_1 – the highest layer; H_2 – middle layer; H_3 – the lowest layer; vegetation stage: – vegetating; ~ – vegetating after fruiting; v – the state of rosette; + – unripe fruits; # – mature fruits; abundance according to Drude: cop1 – very scattered; sp – scattered (few); gr – groups.

The dead cover is fragmentary consisting of the leaves of tree species and dead herbs. There are diggings of mouse-type rodents. The soil is forest black soil, carbonate, low forest covered, low-eroded, medium-humus, medium-loamy on forest loams.

2.5–0 cm. The forest floor consists of semi-rotten, semi-stuck wood species, brown rotten wood that separated from the soil.

0–25 cm horizon. The horizon is dark gray, almost black, moist, humus-sedentary, loose, with many roots, coarse-pored. It almost entirely consists of the excrements of earthworms and other representatives of soil mesofauna (Fig. 2a). There is a large number of plant residues at different stages of development. The color is dark brown, almost black, homogeneous throughout the ground slide due to the high content of organic compounds. The plasma of humus is clayey, homogeneous throughout the ground slide, anisotropic, but largely hidden by organic compounds, the glowing is speckled. Plant residues are mostly fresh and low-rotten. Humus consists of humus clusters and colloform fresh-brown humus. The type of humus is mull. The visible pore space occupies a significant area (40–45%). Pores are of irregular structure, interaggregate. This area is dominated by aggregates of zoogenic origin (coprolites), which are mainly isometric and slightly elongated, of organic-mineral structure. Interaggregate pores contain remains of small invertebrates. Microstructure is of an aggregated and spongy type. Elemental microstructure is plasma-silty. The skeleton is dominated by quartz and feldspars of isometric and slightly elongated shape.

25–60 cm horizon. Dark gray, moist, granular and fine granular, soft, loamy. Effervescence of $CaCO_3$ is effected by HCl at a depth of 42 cm. The color is dark brown, uniform throughout the ground slide, along with dense, opaque organic clusters of round shape with a diffusive outline. The plasma is humus-clayey, homogeneous throughout the ground slide, anisotropic (Fig. 2b). The glow is speckled, inhomogeneous throughout the ground slide, organic matter consists of slightly rotten and fresh plant residues. The humus includes a sufficient number of scattered humus clusters and light brown humus. The type of humus is mull. Pores are of interaggregate irregular shape, there are also round inwardly aggregate pores and cracks (Figs 2c, d). Visible pores occupy a sufficiently large area (30–40%). Aggregates are mostly coprolite-type, isometric, with organic-mineral structure, of a round and isometric shape. Microstructure is aggregated and spongy (Fig. 2d). Elemental microstructure is plasma-silty.

The skeleton is dominated by quartz and feldspars of slightly elongated isometric shapes of various sizes, mostly medium-rounded.

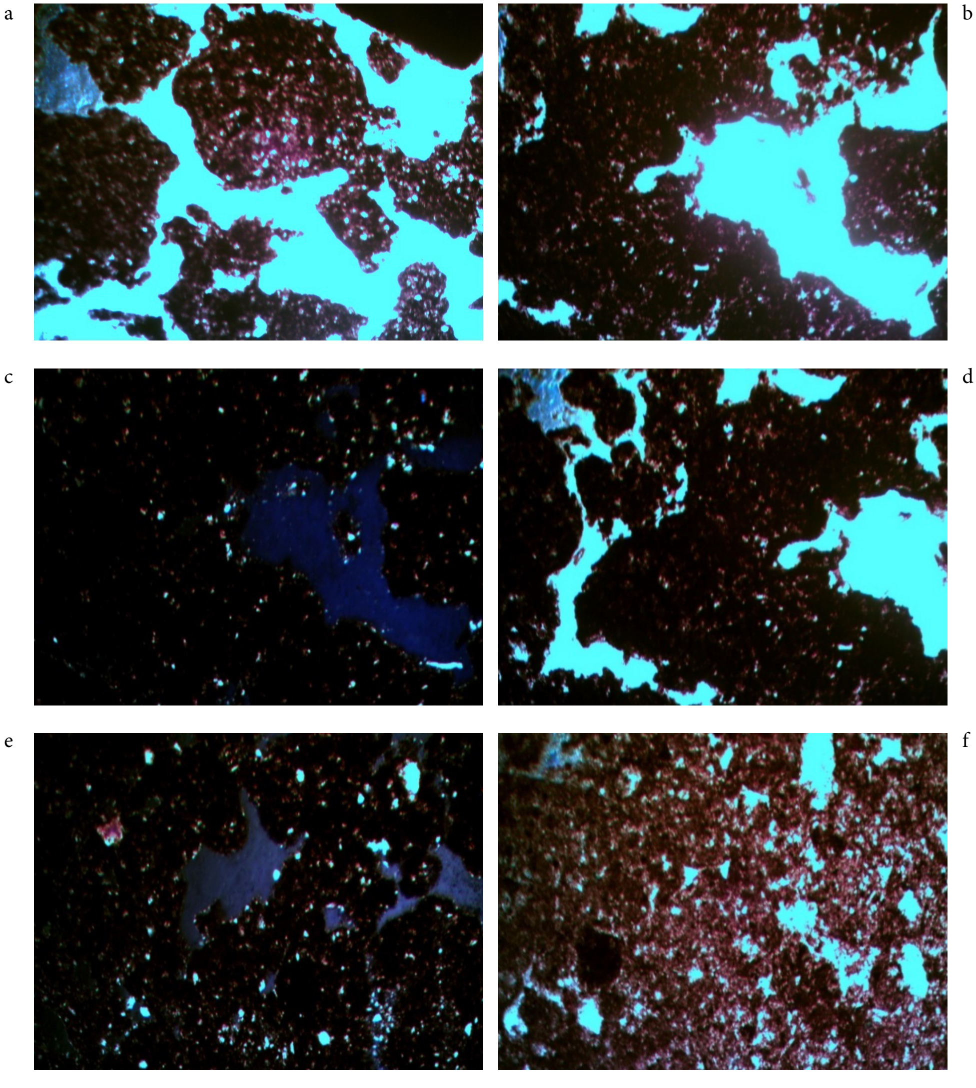

Fig. 2. Micromorphological structure of soils of the northern ravines of Dnipropetrovsk region, ×60:
a – nicols are parallel, there is coprolite in pore space (0–25 cm); b – nicols are parallel, a microstructure is of an aggregate and spongy type (0–25 cm); c – nicols are crossed, humus–clay anisotropic plasma, elemental plasma-silty microstructure (25–60 cm); d – nicols are parallel, the system of pores, skeleton, plant remains (25–60 cm); e – nicols are crossed, pores, skeleton (60–85 cm); f – humus carbonate-clay plasma, anisotropic, visible porosity takes much less space.

60–85 cm horizon. Dark gray, with a brown shade, gradually becoming lighter, noticeably dense, granular and fine granular, loamy. The transition between horizons is gradual. The color is brownish, heterogeneous due to less humus content. The plasma is humus-carbonate-clayey, inhomogeneous, anisotropic. The glow is speckled throughout the ground slide (Fig. 2e). The walls of the pores have anisotropic films (cutans), of mineral structure, which is the result of lessivage. There are few plant remains, mainly half-rotten. Organic compounds are much less. Microstructure is spongy, not aggregated. Pores are mostly irregular, rounded, of a narrow elongated shape (Fig. 2f). There is a large number of parallel and intersecting cracks.

Microstructure is of a spongy type. Elemental microstructure is plasma-silty. The skeleton is dominated by feldspars and quartz of various sizes, dominated by isometric shapes, slightly rounded.

85–120 cm horizon. Dark brown with a straw-colored shade, which is getting much lighter and denser at depths. The color of a sample is from light brown to brown. There are dense opaque rounded organic clusters with a diffusive outline. Elementary microstructure is plasma-silty. The plasma is humus-carbonate-clayey, inhomogeneous, anisotropic. The glow is speckled throughout the ground slide. The walls of the pores have signs of lessivage. The plant remains are scarce, mainly slightly rotten. Organogenic components are much fewer. The type of humus is mull having the same shapes, but in a much smaller number. Microstructure is of a spongy type. Elementary microstructure is plasma-silty. The skeleton is dominated by feldspars and quartz of various sizes, mainly isometric. Pores are narrow and elongated, irregular. Visible pores take much less (10–15%) area.

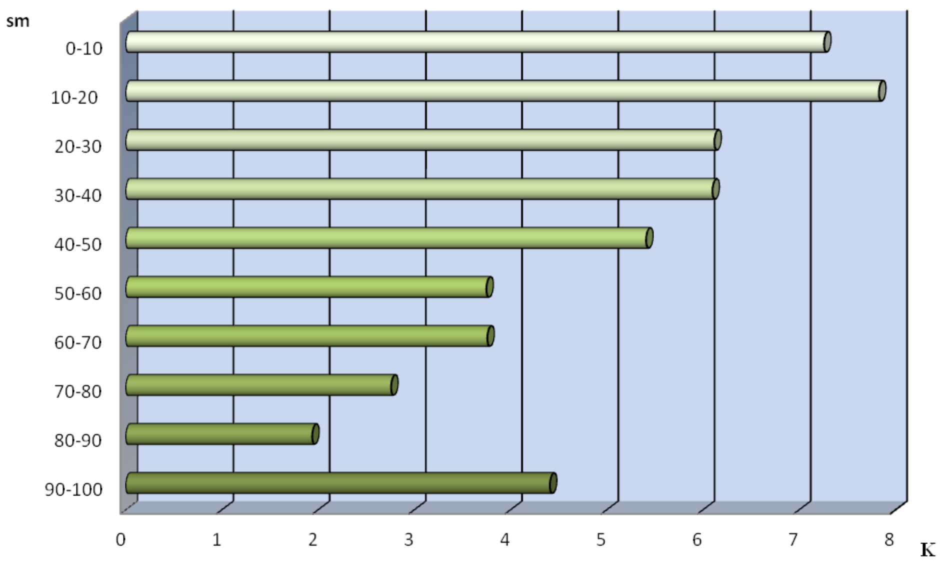

Fig. 3. The coefficient of pedality of the ravine soils.

The deeper the horizon is, the lower the coefficient of pedality (K) becomes (Fig. 3). Maximum value of K is in the 10–20 cm horizon (7.83 ± 0.81), and minimum value is in the 80–90 cm horizon (1.94 ± 0.15). The sum of 0.5–2.0 mm aggregates has a fairly high content. The greatest value of this indicator is in the 10–20 cm horizon (65.98 ± 2.07%), and the smallest is in the 50–60 cm horizon (30.51 ± 0.74%) (Fig. 4).

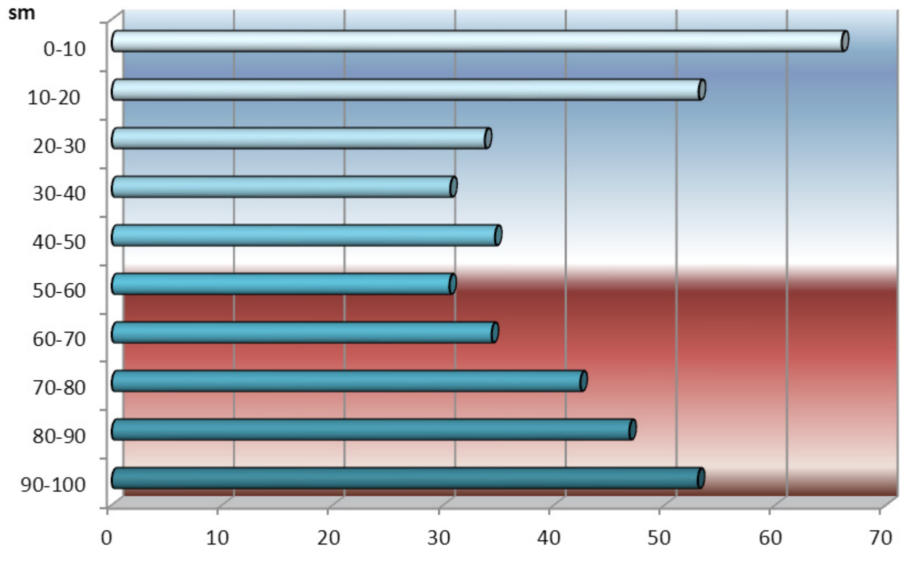

Fig. 4. The sum of 0.50–2.00 mm aggregates of the ravine soils.

The biometric correlation analysis as a combination of methods for detecting correlation dependence between two or more random features has been used by us to obtain more accurate information on the nature and strength of the relationship between the characteristics of the studied soils. The correlative connection is characterized by the correlation coefficient r. We have examined the relationship between two indicators of the aggregate analysis results: X_i value is the sum of aggregates having size from 0.5 to 2.0 mm (Σ0.5–2.0 mm), Y_i value is the coefficient of pedality (K) of the same samples of the ravine soil of the middle third of the slope of the southern exposure. The results of the calculations have shown that the correlation coefficient between the indicators Σ0.5–2.0 mm and K is 0.76, which is a high correlation.

The deeper the horizon is, the lower the water stability of soil aggregates becomes (Table 2). The coefficient of pedality reaches maximum value (90.01 ± 3.07% and 86.13 ± 4.11%) in the 0–10 cm horizon (1.00–2.00 mm fraction and 0.50–1.00 mm fraction, respectively) and minimum value (37.78 ± 3.84%) in the 90–100 cm horizon (fraction of 0.25–0.50 mm). The

T a b l e 2. Water stability of structural aggregates of the ravine soils.

Horizon (cm)	Fracture (mm)	Aggregate structure (%) as a result of percolation			Total sum of all aggregates (%)
		1.00	0.50	0.25	
1	2	3	4	5	6
0–10	1.00–2.00	54.18 ± 1.03	23.89 ± 0.76	11.94 ± 0.56	90.01 ± 3.07
	0.50–1.00	61.71 ± 1.62	16.92 ± 2.08	6.50 ± 0.09	86.13 ± 4.11
	0.25–0.50	13.98 ± 1.02	34.15 ± 1.74	8.78 ± 0.19	56.91 ± 3.08
10–20	1.00–2.00	34.29 ± 0.97	21.06 ± 2.19	26.02 ± 0.04	81.37 ± 3.75
	0.50–1.00	16.08 ± 0.87	41.40 ± 1.77	16.69 ± 0.61	74.17 ± 3.94
	0.25–0.50	11.08 ± 0.73	24.39 ± 1.50	14.76 ± 0.24	50.23 ± 2.88
20–30	1.00–2.00	29.91 ± 1.81	36.51 ± 1.03	8.31 ± 0.28	74.73 ± 3.61
	0.50–1.00	17.12 ± 0.63	35.13 ± 1.27	11.68 ± 0.99	63.93 ± 3.15
	0.25–0.50	11.22 ± 1.02	26.04 ± 2.05	7.11 ± 0.08	44.37 ± 3.37
30–40	1.00–2.00	24.96 ± 1.84	29.99 ± 0.71	8.58 ± 0.81	63.53 ± 2.62
	0.50–1.00	26.05 ± 2.09	28.17 ± 1.31	3.65 ± 1.04	57.87 ± 4.78
	0.25–0.50	16.54 ± 0.69	28.12 ± 1.66	12.36 ± 0.32	57.02 ± 3.87
40–50	1.00–2.00	34.05 ± 1.65	13.02 ± 1.32	9.55 ± 0.47	56.62 ± 3.94
	0.50–1.00	20.11 ± 1.14	21.87 ± 0.84	8.03 ± 0.30	50.01 ± 2.79
	0.25–0.50	18.20 ± 0.09	13.01 ± 2.06	12.05 ± 1.13	43.26 ± 3.70
50–60	1.00–2.00	32.12 ± 2.08	19.06 ± 1.91	2.43 ± 0.05	53.61 ± 1.83
	0.50–1.00	17.22 ± 0.86	21.07 ± 1.36	3.74 ± 0.52	42.03 ± 3.08
	0.25–0.50	9.04 ± 0.30	25.36 ± 1.17	3.38 ± 0.08	37.78 ± 3.84
60–70	1.00–2.00	29.38 ± 3.11	23.06 ± 1.29	3.73 ± 0.78	56.17 ± 2.08
	0.50–1.00	20.71 ± 3.14	23.02 ± 2.19	7.86 ± 0.75	51.59 ± 2.93
	0.25–0.50	12.39 ± 1.61	16.83 ± 2.71	13.31 ± 1.73	42.53 ± 3.84
70–80	1.00–2.00	21.36 ± 0.67	24.05 ± 1.58	5.76 ± 1.08	51.17 ± 2.06
	0.50–1.00	18.69 ± 1.99	25.65 ± 3.06	6.84 ± 2.68	50.18 ± 1.07
	0.25–0.50	11.51 ± 2.71	18.94 ± 0.88	17.63 ± 1.51	48.08 ± 2.17
80–90	1.00–2.00	28.14 ± 1.31	19.31 ± 2.55	3.57 ± 0.07	51.02 ± 4.18
	0.50–1.00	23.61 ± 3.17	18.64 ± 2.11	6.42 ± 1.15	48.67 ± 3.21
	0.25–0.50	18.01 ± 0.18	18.99 ± 1.98	10.14 ± 0.65	47.14 ± 3.51
90–100	1.00–2.00	28.31 ± 0.22	17.26 ± 3.05	4.63 ± 0.24	50.20 ± 4.08
	0.50–1.00	22.44 ± 0.88	18.09 ± 2.41	7.53 ± 0.60	48.06 ± 4.76
	0.25–0.50	12.29 ± 1.04	18.04 ± 0.84	16.11 ± 0.66	46.44 ± 3.43

Note: 0.25–1.00 mm aggregates, as being the most productive for black soil, were analyzed; the study was conducted three times.

coefficient of correlation of water resistance indicators of 1.00–2.00 and 0.50–1.00 mm aggregate fractions is 0.97, which is a very high correlation.

The determination of the correlation between two indicators—the coefficient of pedality (K) and water stability of soil aggregates of 1.00–2.00 mm size—has identified a high correlation coefficient of 0.76.

Discussion

Micromorphological studies have shown a high degree of soil aggregation. Upper horizons are of dark gray, almost black color, homogeneous throughout the area of the micromorphological ground slide due to the high content of organic compounds. The horizon is moist, humus-eluvial, loose, rich in roots, coarse-pored. The upper layer of the soil is solid and humus and almost completely consists of excrements of earthworms and other representatives of the soil mesofauna. The main structure-forming role belongs to dew-worms and small invertebrates. The plasma of humus is clayey, homogeneous throughout the ground slide, anisotropic, but largely hidden by organic compounds, the glow is speckled. The plant remains are fresh and slightly rotten. Humus consists of humus clusters and collomorphic fresh-brown humus. The type of humus is mull. The small areas of aggregated and spongy microstructure prevail. Visible porosity occupies a significantly large area. In the upper horizons there are a great number of large, mainly round and oval pores, which contributes to good aeration at great depth. The deeper it gets, the smaller the area of visible surface is, decreasing from 55% to 5%, the soil becomes denser and the pores gradually turn into cracks. The upper horizons are rich in isometric and slightly elongated aggregates of zoo origin (coprolites) with organic and mineral structure. Interaggregate pores partly incorporate residues of small invertebrates. Microlayers are mostly aggregated and sometimes spongy, depending on the microzone of the soil slide. Elemental microstructure is of a plasma-pulverescent type. The skeleton mainly consists of medium-rounded quartz and feldspars of isometric and slightly elongated shape. The soils are carbonate, the effervescence of $CaCO_3$ effected by HCl occurs at 42 cm depth.

The color of lower horizons varies from light brown to dark brown with a pale-yellow shade, becoming much lighter and thicker at depth. There are areas of dense opaque organic clusters of a round shape with a diffusive outline. The plasma is humus-carbonate-clayey, inhomogeneous, anisotropic. The glow is speckled throughout the ground slide. The walls of the pores incorporate anisotropic films, of mineral structure, which points to lessivage. The plant remains are scarce, mostly slightly rotten. There are much fewer organogenic compounds. The type of humus is mull having the same shapes, but in a much smaller quantity. Pores are narrow, elongated, and irregular. Visible porosity occupies a much smaller area (10–15%). Elemental microstructure is of a plasma-silty type.

The results of determining the aggregate composition of soils indicate a high aggregation of humus horizons. The coefficient of soil structure (*K*) reaches the greatest value (7.83 ± 0.81) in the 10–20 cm horizon, while the lowest value (1.94 ± 0.08) can be seen in the 80–90 cm horizon. The deeper the horizon is, the less the sum of 0.5–2.0 mm aggregates becomes. The greatest value of this coefficient can also be indicated for humus horizons (65.98 ± 1.63) in the 0–10 cm horizon.

The deeper the horizon is, the lower the water stability of soil aggregates becomes. The maximum value of this indicator is 90.01 ± 3.07% in the 0–10 cm horizon (1.00–2.00 mm fracture). The greater the depth is, the more the indicator of this fracture falls gradually up to 50.20 ± 4.08% at 90–100 cm depth. The water resistance of 0.50–1.00 mm fracture is also very high in the upper horizons (86.13 ± 4.11%) in the horizon of 0.50–1.00 cm and gradually decreases, the greater the depth becomes, up to 48.06% at 90–100 cm depth. The water resistance indicators of 0.25–0.50 mm fracture are the lowest and range from 56.91 ± 3.08% to 46.44 ± 3.43%.

The coefficient of correlation of water stability indicators of 1.00–2.00 and 0.50–1.00 mm aggregate fractions is 0.97, which is a very high correlation. The determination of the correlation between two indicators—the coefficient of pedality (*K*) and water resistance of soil aggregates of 1.00–2.00 mm size (as the highest value of three fractions)—has shown a high correlation coefficient of 0.76. This testifies that different qualitative indicators of soil properties synchronously decrease the deeper the soil slide is.

Earlier we investigated the properties of the ravine soils on the example of the middle third of the slope of the northern exposure (Bozhko, Bilova, 2010). The coefficient of soil pedality here turned out to be extremely high—10.53 ± 1.22 and 12.74 ± 1.79 in the 10–20 cm horizon and 30–40 cm horizon, respectively, while water stability of structural aggregates reaches 95.07 ± 2.17% and the power of the humus horizon is greater. The comparison between the coefficient of soil pedality and water stability of two ravine slopes is presented in Table 3.

T a b l e 3. The comparison between the coefficient of soil pedality and water stability of two ravine slopes.

Horizon (cm)	**The slope of the southern exposure**		**The slope of the northern exposure**	
	K	***J***	***K***	***J***
0–10	7.26 ± 0.94	90.01 ± 3.07	7.05 ± 1.06	94.67 ± 1.16
10–20	7.83 ± 0.81	81.37 ± 3.75	10.53 ± 1.22	95.07 ± 2.17
20–30	6.12 ± 0.17	74.73 ± 3.61	8.53 ± 1.51	86.75 ± 1.34
30–40	6.10 ± 0.21	63.53 ± 2.62	12.74 ± 1.79	93.62 ± 2.08
40–50	5.41 ± 0.51	56.62 ± 3.94	3.67 ± 0.74	67.94 ± 2.71
50–60	3.75 ± 0.44	53.61 ± 1.83	4.69 ± 0.85	83.15 ± 3.17
60–70	3.76 ± 0.39	56.17 ± 2.08	4.39 ± 1.01	80.37 ± 2.61
70–80	2.76 ± 0.11	51.17 ± 2.06	1.98 ± 0.08	81.55 ± 1.96
80–90	1.94 ± 0.24	51.02 ± 4.18	2.23 ± 0.37	64.16 ± 2.48
90–100	2.41 ± 0.19	50.20 ± 4.08	2.24 ± 0.71	81.32 ± 3.06

Notes: *K* – coefficient of pedality; *J* – water stability of 1.00–2.00 mm aggregates.

This difference is explained by the following factors: on the slope of the northern exposure, the type of forest vegetation is a fresh clay loam, in contrast to the southern exposure where it is a much fresher clay loam; the type of forest biogeocoenosis is a fresh lime-ash-maple wood. The light structure is half-shadowy. The density of the tree crown is 0.8. Such conditions are the most favorable for soil formation and active processes of soil humification.

Conclusion

The study of the soil structure and aggregation, water stability of aggregates, and ecological and micro-morphological features of soils of the ravine forests of Pre-Dnipro region

(Ukraine) on the example of the northern variant of the ravine forest "Kapitanivskiy" has identified a high degree of aggregation of the upper horizons of the soil slide. The structure is of a zoogenic origin. The aggregates of mainly coprolite nature contain well-rotten plant remains. The dark gray, almost black color throughout the area of the micromorphological slide is due to a large number of organic compounds, which points to active processes of humification. Finely dispersed humus includes a large number of equally spaced humus clusters. The type of humus is mull. The area of the visible surface of the pores in the upper horizons of the soil profile is fairly large (40%). Pores are round and elongated. Typically, remains of small invertebrates can be found in the pores. The deeper the soil slide is, the smaller the area of visible pores (from 55 to 5%) together with aggregation becomes. Correlating with micromorphological characteristics, the water resistance of structural aggregates reaches high values (90.01 ± 3.07%) in the upper mummified coprolite horizons of the soil slide, decreasing at depths. The coefficient of pedality in ravines reaches 7.83 ± 0.81. The sum of 0.5–2.0 mm aggregates is 65.98 ± 2.07%.

Comparing the soil properties of the southern and northern exposure of the object under study, we have come to the conclusion that the soil structure and aggregation, water stability of aggregates, and soil micromorphological indicators are much better on the slope of the northern exposure. Consequently, more favorable environmental conditions here, especially microclimatic, are the most suitable for active processes of humification and microstructure formation.

In general, the soils of the northern ravine forests of Pre-Dnipro region (Ukraine) are characterized by an active biogenic microstructure formation, which results in significant aggregation and looseness of the microstructure, which greatly increases the fertility of these soils.

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