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TOTAL AND WATERSOLUBLE ORGANIC MATTER CONTENT IN SOIL UNDER VARIOUS METHODS OF FORESTRY

Water-base organic compounds are among the most labile fractions of soil organic matter. Their content are considered a sensitive indicator of soil quality and changes quantitatively under the influence of anthropogenic pressure. The objective of this paper was to evaluate the impacts of different felling systems on total and water extractable organic carbon content in soil. The soil samples were taken from 50 cm depth soil profile with 5 cm step. Total organic carbon (TOC), cold water extractable organic carbon (CWEOC) and hot water extractable organic carbon (HWEOC) contents in soil were determined. The highest TOC content was found in the soil under the old-growth hornbeam-oak forest: 49—63 mg/ g and 12—16 mg/ g in a top 0—5 cm and 0—50 cm layers respectively. Gradual, group-selection and clear felling of hornbeam were attended by significant transformations of organoprofile and decrease of TOC content especially in top 15 cm layer. However, fractional contents of cold and hot water extractable organic carbon increased with depth. The results of this research indicate that among the studied scenarios of the forest management, gradual felling caused minimal changes of soil organic matters.

Key words: soil organic matter, labile humus, water extractable organic carbon, dissolved organic matter, forest soil, deforestation, felling.

Labile organic matter in soils plays an important role in functioning of terrestrial ecosystems and is closely associated with many important chemical, physical and biological processes (Mathers et al., 2000; Chen et al., 2004). It consists of non-humified materials of different nature such as hydrocarbon monomers, low molecular weight organic acids, amino acids and low molecular weight proteins (Haynes, 2005). The most active and mobile fractions of labile organic matter in soils are soluble in water (Bu et al., 2011).

Dissolution of soil organic compounds in water leads to initiation of the nutrients flow from terrestrial into aquatic ecosystems. Nowadays, the rates of dissolved organic carbon (DOC) outflow from terrestrial ecosystems increases (Worrall, 2003). The loss of soil organic matter due to washout of dissolved organic compounds is the second largest carbon flow after soil respiration (Wetzel, 1992). The increase of DOC concentration in surface waters of England and Wales is observed during the last 40 years and this process reflects the worldwide trend (Freeman, 2004). An additional point is that soil CO_2 efflux is influenced by the quantity and quality of soil organic matter (Kim et al., 2012). Soluble in water organic materials are important and readily decomposable substrates for microorganisms (Marschner, Bredow, 2002). This fraction of soil organic matter (SOM) is closely related to the production of greenhouse gases due to its high biodegradation rates (Gregorich et al., 2003). Thus, the management of soluble in water organic carbon pools and fluxes in ecosystems is also important in the context of global climate changes.

Water extractable organic matter is a subject of wide range of anthropogenic activities. According to Yanai et al. (2003), quantitative and qualitative evaluation of DOC changes in soil due to logging and agricultural use of deforested territories is one of the most important problems of modern soil ecology and soil science. Deforestation influences the transportation of DOC from forest floor to mineral layers of soil and changes conditions of SOM mineralization (Likens, Bormann, 1995).

Despite the importance of water soluble SOM in functioning of terrestrial ecosystems the peculi-

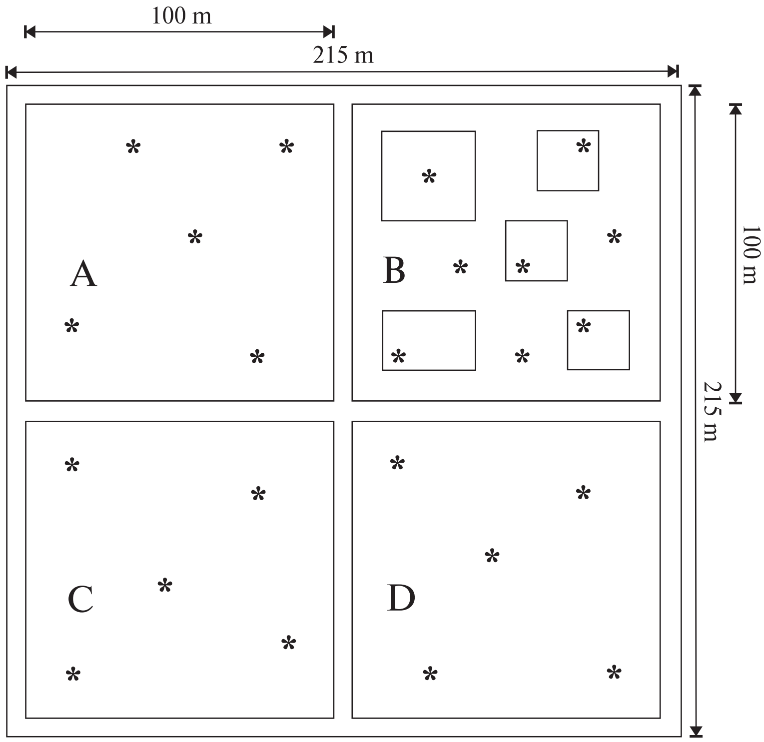

Fig. 1. Scheme of study area with experimental plots and sample points

arities of its migration and transformations in forest ecosystems remain largely unclear (Guggenberger, Kaiser, 2003). The majority of studies are focused on TOC and DOC dynamics after forest harvest with or without residue removing (Yanai et al., 2003). However, they did not pay enough attention to the influence of felling systems on organic carbon content in soil.

For this reason, the objectives of our study were: (i) to evaluate the impact of various forest management scenarios in old-growth hornbeam-oak forest on total and soluble in water SOM content in soil and (ii) to explore the possibilities of dissolved organic compounds migration down the soil profile under the influence of different felling systems.

Materials and methods

Study area

The experiments were carried out on four plots (100 × 100 m) located in typical for Central and Eastern Europe hornbeam-oak forest (49° 32' N., 23° 20' E.), in the upper part of Dniester basin, Western Ukraine (Fig. 1). The field experimental plots were established in 2006. The first plot — in pristine old-growth hornbeam-oak forest, the second — in an adjacent part of forest, where gradual felling of hornbeam was carried out (Tabl. 1), the third plot — in forest, after group-selection felling of hornbeam made by forming five 300 m^2 gaps. Fourth sample plot was located in the forest after clear felling of second storey.

The soils in study area were *Gleyic Albeluvisols (ABg)*. For the last 30 years mean annual bulk precipitation was 697 mm, the annual average temperature was 7.8 °C and the sum of active temperatures — about 2400—2600 °C.

Soil sampling and analysis

For this study the soil samples were taken from 50 cm depth soil profile, with a 5 cm step. Soil sampling was held in October 2009, the third year after felling. The samples were taken from three sides of the soil pit and with a special bore from five points located less than 5 m from pit. Each experimental plot included 5 sample points. Fresh soil samples were passed through 3 mm sieve and mixed samp-

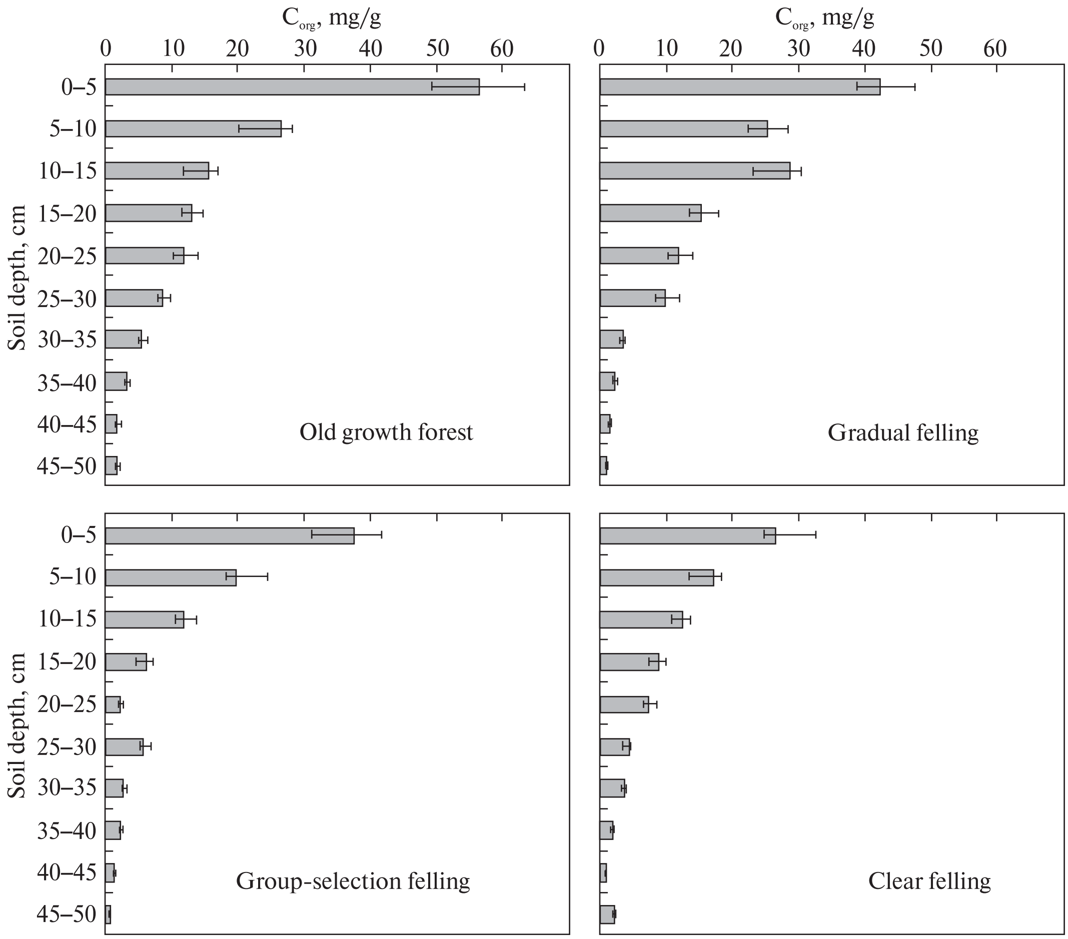

Fig. 2. Total organic carbon content in soils under various forest management scenarios (range plots with medians, maximums and minimums)

les for each 5 cm layer were made. For all the analyses, described in this study, the soil samples were air-dried. The chemical composition was provided in dry matter. The total organic carbon (TOC) content was determined by wet combustion method (ISO 14235, 1998). The absorbance of the obtained solutions was measured spectrophotometrically on SPEKOL 2000 (Analytik Jena). Content

Table 1. **Standing timber volumes on experimental plots before and after felling, m^3/ha**

Forest management scenario	Standing timber volume			
	before felling		after felling	
	oak	hornbeam	oak	hornbeam
Old growth forest	128	32	128	32
Gradual felling of hornbeam	127	43	127	18
Group-selection felling of hornbeam	131	38	118	21
Clear felling of hornbeam	122	41	122	0

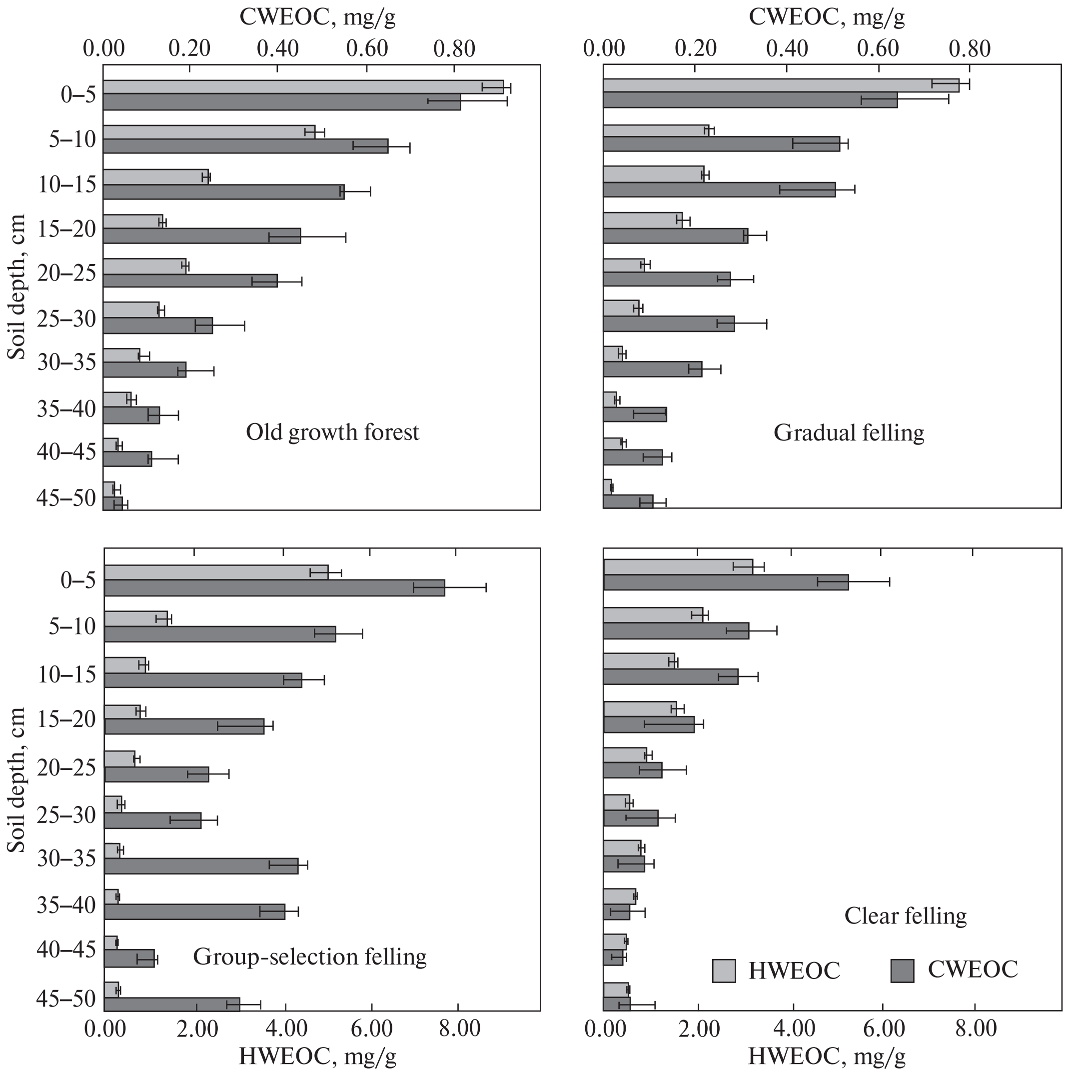

Fig. 3. Water extractable organic carbon content in soils under various forest management scenarios (range plots with medians, maximums and minimums)

of cold and hot water extractable organic carbon was determined according to the method of Haynes and Francis (1993) in modification of Ghani et al. (2003) that consists of two-step water extraction. The first step included water hydrolysis at 20 °C for 30 min and caused the removal of the most labile organic compounds. The fraction obtained is known as cold water extracted organic carbon (CWEOC). Quantitatively, it is close to the dissolved organic carbon (DOC) content measured in the soil solution (Chantigny, 2003). The second step included water extraction at 80 °C for 16 h. The procedure removes more stable compounds which form the reserve of nutrients and energy for plants and soil microorganisms. The fraction obtained is known as "hot water extracted organic carbon" (HWEOC). In this study, we excluded CWEOC from HWEOC to guarantee the differential evaluation of these two fractions of soil organic matter. In each experiment, five replicates were taken for each soil sample.

Statistical analysis

Statistical analysis of experimental data was made according to the recommendations of S. Glantz

(1997). For comparisons of multiple groups, the nonparametric Kruskal–Wallis test followed by Conover post hoc test were used. Linear and exponential regressions analyses were used to model the profile changes of TOC, CWEOC and HWEOC contents in soil with depth. The difference was considered significant when $p < 0.05$. Statistical analyses were performed using the MS Excel 2007 with add-in AtteStat 12.1.7.

Results and Discussion

The highest content of TOC was found in the organic horizons and decreased with depth (Fig. 2). The soil organic carbon content in soil profile under the old-growth forest was the highest in the top 5 cm layer (49–63 mg/g) and decreased exponentially with depth, reaching only 1.5–2.0 mg/g at 45–50 cm.

On all other experimental plots a significant ($p < 0.05$) decrease of TOC content with the increase of the intensity of felling was observed. The major transformations were found in the upper 15 cm layer, with maximum in depth 0–5 cm. The results obtained indicate the simplification of well stratified forest soils. The most significant changes were found in the subsurface soil layers. High difference between TOC content in top layers is usual for forest soils. For example, in *Cambisols* under beech forest (*Fagus sylvatica* L.) in 5 cm subsurface layer of soil TOC content was 48 and only 26 mg/g in layer 5–10 cm and in *Cambisols* under oak forest (*Quercus cerris* L.) these values were 46 and 20 mg/g respectively (Buzek et al., 2009).

In our research the changes in total organic carbon content on top layers of soil were attended by forming new zones of TOC accumulation in soils after hornbeam felling. These processes could be explained by changing of the immobilization-mineralization balance in soil after the elimination of edificator and migration of dissolved organic matter down the profile (Fig. 3). In the majority of cases not only TOC but also CWEOC and HWEOC contents were the highest in subsurface layer and decreased with depth. Strong correlations ($0.77 < \rho < 0.99$, $p < 0.01$) between quantitative profile changes of SOM and water-extractable organic matter fractions were found on every experimental plot. In addition, strong correlations between quantitative profile changes of CWEOC and HWEOC were found in control ($\rho = 0.99$, $p < 0.01$), after gradual felling ($\rho = 0.98$, $p < 0.01$) and after clear felling ($\rho = 0.94$, $p < 0.01$), and much weaker in soil after group-selection felling of hornbeam ($\rho = 0.73$; $p = 0.02$).

With the increase of felling intensity in forest ecosystem, a lot of ready for mineralization organic compounds migrated downwards the soil

Table 2. **Content of cold (CWEOC) and hot water extractable organic carbon (HWEOC) in % of total organic carbon (TOC), n=5 for each soil layer (old-growth forest, gradual felling and clear felling)**

d, см	Old growth forest		Gradual felling		Group-selection felling		Clear felling	
	CWEOC	HWEOC	CWEOC	HWEOC	CWEOC	HWEOC	CWEOC	HWEOC
0–5	1.45	16.18	1.54	18.51	2.04	13.3	2.04	12.12
5–10	2.45	18.27	2.07	9.12	2.64	6.84	1.86	12.55
10–15	3.60	15.72	1.78	7.60	4.19	7.91	2.34	12.52
15–20	3.52	10.55	2.13	11.54	6.01	11.52	2.26	18.07
20–25	3.43	16.22	2.52	7.84	11.01	27.75	1.73	12.14
25–30	2.92	15.17	3.07	7.68	3.83	4.74	2.86	12.47
30–35	3.64	16.28	7.95	13.26	16.67	8.91	2.60	23.05
35–40	4.38	20.54	8.18	14.47	18.61	8.37	3.65	45.99
40–45	6.67	19.39	15.01	41.25	8.40	10.08	6.82	63.73
45–50	2.42	15.15	33.33	30.00	50.02	25.04	2.76	23.76

profile and accumulated on waterproof surfaces located out of rhizosphere. Maximal imbalance between labile (CWEOC) and more stable (HWEOC) fractions of SOM was found in soil profile after group-selection felling. On this experimental plot at the depth of 30–40 cm 0.35–0.45 mg/g of CWEOC was detected. This content was about 2.5 times higher than in soil of old growth forest and after gradual felling and more than 6 times higher than in soil after clear felling of hornbeam. Although to compare the profile changes of water-extractable organic matter contents on different experimental plots it is necessary to take into account uneven TOC content. Proposed results in a differential form — in percentage of TOC — makes them more convenient to interpret (Partyka, Hamkalo, 2010).

Gradual hornbeam group-selection and clear felling in old-growth oak-hornbeam forest caused downward migration of dissolved organic matter (Tabl. 2). Content of both extracted fractions of labile SOM increased with depth. It should be noted that in forest soils after gradual and group-selection felling of hornbeam the configurations of organoprofiles were complicated with many peaks and zones of labile SOM accumulation. At the same time, profile changes of CWEOC and HWEOC relative content in control and after clear felling of hornbeam have much in common: simple organoprofile, peaks on depth 40–45 cm and high HWEOC/CWEOC ratio which increased with depth.

Mobilization of stable organic components and their redistribution in soil profile means that the observed forest management scenarios determine quantitative and qualitative characteristics of soil organic matter. Cutting the edificator also causes outflow of soluble in water organic materials from rhizosphere due to evapotranspiration decrease (Likens, Bormann, 1995). Partly they can be adsorbed by minerals. Although each year the losses of dissolved organic carbon from forest soil average 1–10 g /m^2 (Guggenberger, Kaiser, 2003).

This study has shown that the intensity of forest management systems significantly influenced the quality and quantity of soil organic matter. The increase of felling intensity in the forest ecosystems is attended by soil organic carbon losses due to SOM mobilization and mineralization. In studied 50 cm soil layer the impacts of each forest management system was determined. The highest quantities of TOC were detected in the soil under the pristine oak-hornbeam forest — between 12.09 and 16.05 mg/g. It decreased by 6, 37 and 44 % after gradual group-selection and clear felling of hornbeam respectively. CWEOC content in control was between 0.32 and 0.42 mg/g. It decreased by 14 and 51 % after gradual and clear felling of hornbeam respectively and increased on 5% in soil after group-selection felling of hornbeam. However, HWEOC content in this variant decreased by 59 %, compared to 2.15–2.40 mg/g in control. In forest soil after gradual and clear felling of hornbeam the decrease was observed in 29 and 49 % respectively. All these changes were attended by the increase of fractional content of water-extractable organic matter with depth of soil profile. The results of this research indicate that among four studied scenarios of forest management, gradual felling caused minimal losses of water extractable organic matter in soil. In natural forests we recommend preferring this type of felling, while intensive systems should be used only occasionally. The current investigation was carried out in temperate broadleaf forest. There is, therefore, a definite need for future research in mixed and coniferous forests that differ from studied ecosystems in SOM quality and quantity.

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ВМІСТ ВАЛОВИХ ТА ВОДОРОЗЧИННИХ ФОРМ ОРГАНІЧНОЇ РЕЧОВИНИ У ҐРУНТІ ЗА РІЗНИХ СПОСОБІВ ЛІСОКОРИСТУВАННЯ

Водорозчинні органічні сполуки — одна з найлабільніших фракцій органічної речовини ґрунту. Їх вміст є важливим індикатором якості ґрунту, зазнаючи кількісних змін під впливом антропогенних впливів. Метою нашої роботи було оцінити вплив різних систем рубок на валовий вміст карбону органічних сполук ($C_{орг}$) та вміст водорозчинних органічних сполук у ґрунті. Зразки ґрунту відбирали до глибини 50 см з кроком 5 см. Проводили визначення вмісту $C_{орг}$, екстрагованого холодною (ЕХВОР) та гарячою (ЕГВОР) водою органічних речовин. Найвищий вміст $C_{орг}$ виявлено у ґрунті під непорушеною грабовою дібровою — 49–63 і 12–16 мг/г у шарах 0–5 і 0–50 см відповідно. Поступова, групово-вибіркова та суцільна рубки граба супроводжувались значними змінами органопрофілю і зменшенням запасу $C_{орг}$, особливо у приповерхневому шарі ґрунту потужністю 15 см. Фракційний вміст ЕХВОР та ЕГВОР з глибиною збільшувався. Із досліджених способів лісокористування рівномірно-поступова рубка спричинила мінімальні кількісні та якісні зміни органічної частини ґрунту.

Ключові слова: органічна речовина ґрунту, лабільний гумус, водорозчинний органічний карбон, розчинена органічна речовина, лісовий ґрунт, знеліснення, рубки.

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СОДЕРЖАНИЕ ВАЛОВЫХ И ВОДОРАСТВОРИМЫХ ФОРМ ОРГАНИЧЕСКОГО ВЕЩЕСТВА В ПОЧВЕ ПРИ РАЗНЫХ СПОСОБАХ ЛЕСОПОЛЬЗОВАНИЯ

Водорастворимые органические соединения — одна из наиболее лабильных фракций органического вещества почвы. Их содержание является важным индикатором качества почвы, подвергаясь количественным изменениям под влиянием антропогенных факторов. Целью нашей работы было оценить влияние разных систем рубок на валовое содержание углерода органических соединений ($C_{орг}$) и содержание водорастворимых органических соединений в почве. Образцы почвы отбирали с глубины 50 см с шагом 5 см. Проводили определение содержания $C_{орг}$, экстрагированного холодной (ЭХВОР) и горячей (ЭГВОР) водой органических веществ. Высокое содержание $C_{орг}$ обнаружено в почве под ненарушенной грабовой дубравой 49—63 и 12—16 мг/г в слоях 0—5 и 0—50 см соответственно. Постепенная, группо-выборочная и сплошная рубки граба сопровождались значительными изменениями органопрофиля и уменьшением запаса $C_{орг}$, особенно в приповерхностном слое почвы мощностью 15 см. Фракционное содержание ЭХВОР и ЭГВОР с глубиной увеличивалось. Из исследованных способов лесопользования равномерно-постепенная рубка вызвала минимальные количественные и качественные изменения органической части почвы.

Ключевые слова: органическое вещество почвы, лабильный гумус, водорастворимый органический углерод, растворенное органическое вещество, лесная почва, обезлесение, рубки.